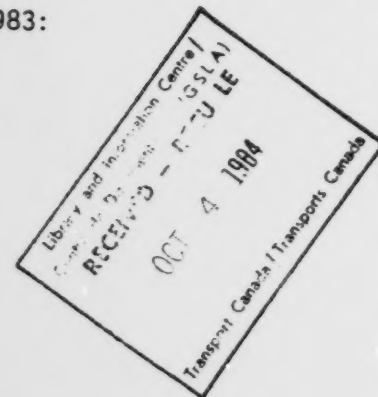


Canadian Track/Train Dynamics
Research Program - 1973 to 1983:
A 10 Year Review



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Services Inc.

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The contents of this report reflect the views of the contractor and not necessarily the official views or policies of the Transport Canada, Transportation Development Centre.

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1. INTRODUCTION

Soon after the introduction of 100-ton freight cars and 3000 HP six-axle locomotives on their systems in the late 1960's and early 1970's, railroads in Canada and the United States began to experience unusually severe rail wear in curves and other track damage on the routes handling those types of vehicles. The incidence of unexplained derailments also increased sharply and it became clear that dynamic interactions between the individual vehicles in these very heavy trains, between individual components of the vehicles and ultimately between the wheels and rail, were straining the system beyond its limit.

Railroads having the necessary technical research capability, such as Canadian National (CN Rail) in Canada and Southern Pacific in the United States, commenced individual in-depth research efforts directed towards a better understanding and resolution of these dynamic interactions. In 1971, the Association of American Railroads (AAR) commissioned the Southern Pacific Transportation Co. to prepare a proposal for a major research effort encompassing operations and design, and on the basis of that proposal, a joint, international, industry/government 3-phase, 10 year Track/Train Dynamics (TTD) Research Program was launched in 1972. Through the contribution of manpower and resources, the two major Canadian railways have participated directly in that program throughout its life.

Transport Canada, through the Transportation Development Centre (TDC), was (and continues to be) represented on the Steering Committee of the International Program and undertook to provide financial support to Canadian railways for related and supporting research in Canada. That undertaking manifested itself through a series of 50/50 cost-shared contracts with CN Rail Research and with the Department of Research of Canadian Pacific Limited, commencing in 1973.

This report summarizes the first ten years of that co-operative government/industry Canadian track/train dynamics research. It was prepared to assist the process of transfer of the technological findings from the work.

2. TRACK/TRAIN DYNAMICS (TTD) CONTRACTS

The first 50/50 cost shared contract between TDC and Canadian National (CN) was signed in August of 1973. In all, the Program to date has included ten successively phased TDC/CN contracts each covering work on a variety of TTD-related subjects plus one additional contract covering the acquisition and evaluation of articulated trucks on a large scale in unit train service.

The initial contract between TDC and Canadian Pacific (CP) was also signed in August, 1973. There have been six successively phased TDC/CP multi-subject contracts, plus one additional contract covering radial truck evaluation.

Generally, the CN contract periods were for one year. The CP contracts normally extended for a longer period.

At the time of award of the contract for preparation of this summary, the work under both the CN Phase X contract and the CP Phase VI contract was incomplete. Those contracts were therefore not included in the Work Statement for this Summary Report, and the work done under those contracts is consequently not reported herein. It will be noted too, in subsequent sections of this report, that certain of the CN technical reports on work done in the latter phases prior to Phase X are still under preparation.

The program has also included two additional contracts, the work under both being associated with the U. S. Federal Railroad Administration extensive Truck Design Optimization Project (TDOP). These contracts were with the Canadian Institute of Guided Ground Transport (CIGGT) and DSL Dynamic Sciences Ltd. as follows:

CIGGT - Rail Wear Economic Analysis

DSL - Computer Modelling Simulations of the Steady-State Curving Performance of Freight Car Trucks.

Unlike the contracts with the railways, the CIGGT and DSL contracts provided for 100% reimbursement to the contractors. Work under these contracts has been completed and is reported on herein.

The basic information concerning each of the contracts reported on herein is provided in Table 1.

Table 1

Contracts - Canadian Track/Train Dynamics Research Program

<u>Contract No.</u>	<u>Contract Title</u>	<u>Contract Period</u>	<u>Contractor</u>
97044	Track/Train Dynamics Phase I	Aug.14/73 - Mar.31/75	CN
OST5 - 0002	" " " " II	Sept.1/74 - Mar.31/76	CN
OST76-00084	" " " " III	Apr. 1/76 - Mar.31/77	CN
OSS77-09013	" " " " IV	Apr.1/77 - Mar.31/78	CN
OSD78-00031	" " " " V	Apr.1/78 - Mar.31/79	CN
OSD79-00097	" " " " VI	Apr.1/79 - Mar.31/80	CN
OSD79-00126	" " " " VII	Apr.1/80 - Mar.31/81	CN
OSD81-00005	" " " " VIII	Apr.1/81 - Dec.1/83	CN
OSD81-00186	" " " " IX	Apr.1/82 - Dec.1/83	CN
OSD79-00040	Acquisition and Evaluation of Articulated Trucks on a Large Scale in Unit Train Service	July 23/79 - Mar.31/83	CN
97179	Track/Train Dynamics Phase I	Aug.27/73 - Mar.31/75	CP
OST5-00042	" " " " II	Mar.1/75 - Sept.30/78	CP
OSD78-00070	" " " " III	Oct. 1/78 - May 15/78	CP
OSD79-00082	" " " " IV	May 15/79 - Mar.31/81	CP
OSD81-00006	" " " " V	Apr. 1/81 - Dec.31/82	CP
OSD81-00074	Wheel Wear Study with Radial Trucks	Aug.5/81 - Jan.31/84	CP
OSD79-00102	Rail Wear Economic Analysis	Jan.23/80 - June 30/83	CIGGT
OSD80-00093	Computer Modelling Simulations of the Steady-State Curving Performance of Freight Car Trucks	Jan.19/81 - Aug.15/81	Dynamic Sciences Ltd.(DSL)

3. OVERVIEW OF THE PROGRAM

Dr. W. J. Harris, Vice-President of the Research and Test Department, Association of American Railways, has defined track/train dynamics as "the dynamic motion that results from the interaction of the vehicles coupled into a train interacting with the track, under given climatic conditions, train handling, grades, curvature and operating policies".(1)

Consideration of this definition reveals that the subject embraces both of the two major railway sub-systems - the physical and the operational. The physical sub-system can be said to include the interactions and dynamic capacities of track, cars, locomotives, train consists, and all associated equipment. The operational sub-system, on the other hand, includes train handling techniques, train make-up, personnel skills and training, and transportation planning. Decisions and policies regarding train make-up, train handling techniques and other operational practices in turn interact with the physical system, increasing the possibility of undesirable or even catastrophic track/train dynamics occurrences.

Work on both of the sub-systems was included in the International Program. The Canadian Program was concerned essentially with the physical sub-system, with some of the earlier CN work being directed towards improvement of the operational sub-system through development of a train handling recorder.

The scope of the Canadian Program was extensive. As already noted, each of the phased railway contracts included investigations (tasks) on several different TTD-related subjects. In all, there were in excess of 300 individual tasks specified in the contracts, exclusive of data analysis and report preparation.

In some instances the individual contract task was complete within itself; that is to say, there was no continuance of that particular subject in succeeding contracts. In others, the contract task, or series of tasks, was in fact only one step in a sequential investigation of the subject, and subsequent steps were included as tasks in a succeeding contract or contracts. Such sequential tasks which constituted a step-by-step progression of one basic task, have, for purposes of comprehension in this report, been consolidated under a single appropriate title for that basic task. Thus, for example, the 42 individual tasks in the CN phased contracts dealing with concrete track ties have been consolidated under one basic task title, "Conduct research on the design and performance of concrete track ties and fastenings". In this way the more than 300 individual contract tasks were reduced to 44 basic tasks for purposes of this report.

(1) Foreword to the Proceedings of the first Conference on Track/Train Dynamics, Chicago, Dec. 15 and 16, 1971.

These basic tasks each fall within one of the following individual, components/sub-components of the physical sub-system:

Locomotive Trucks

Freight Car Trucks and Wheels

Track

Bridges

Vehicle and Train Dynamics

Rail/Wheel Interface

The 44 basic tasks, grouped under those headings, are listed in Table 2.

Summarizations of the investigations conducted in each of the basic tasks appear in Section 4 of this report; however, a more generalized overview of the work, segregated by component/sub-component, is first provided below.

3.1 Locomotive Trucks

This work was undertaken as the consequence of growing evidence in the very early 1970's that GM SD-40 (6-axle) locomotives were introducing excessive lateral curving forces into the track. On CN, special speed restrictions for these locomotives were placed on all curves over 4 degrees as an interim measure to reduce track damage and risk of derailment.

In the initial CN work, possible truck modifications to effect a reduction in lateral curving forces produced by the locomotives were identified. A comprehensive computer program was developed to study the quasi-steady lateral curving forces of locomotive trucks and potential beneficial modifications evaluated. On the basis of the findings from the evaluation, certain modifications were made to one SD-40 locomotive and a test program was set up and implemented to evaluate the curving performance of the modified unit. The results were positive and subsequently all GM SD-40 units in the CN fleet were similarly modified.

CP carried out extensive tests and measurements of the curving performance of three types of 3-axle locomotive trucks. This work generated valuable information concerning the effect of wheel profile, rail profile and high rail flange lubrication on locomotive curving performance.

3.2 Freight Car Trucks and Wheels

The work on this component constituted one of the major elements of each of the contracts with each railway over the ten year period. As may be seen from Table 2, it included a total of 15 of the 44 basic tasks.

This work was undertaken as the result of clear evidence that the accelerating rail wear and other track damage being experienced in curves was attributable to the curving forces generated by the growing fleet of 100-ton freight cars being operated.

Efforts were initially directed towards development of a capability to measure the curving forces. To this end, both CN and CP developed instrumentation for measuring forces introduced into the track in curves along with equipment to measure wheelset angle-of-attack.

Extensive field measurements were made by both groups of researchers to evaluate the effectiveness of different wheel profiles in reducing lateral curving forces, improving the stability of empty vehicles at higher speeds on tangent track, and in reducing wheel and rail wear. Wheel (and rail) profilometers to aid in this latter effort were developed. New and improved computer programs to assist in the research work were developed. Hydraulic interbogie coupling equipment of Swiss design was evaluated for its effectiveness in reducing lateral curving forces.

The work on conventional trucks was followed by a comprehensive research, development and evaluation effort on self-steering freight car trucks. One of the major CN tasks carried the development of a U.S. - designed retrofit for freight car trucks, to provide articulation capability, to practical implementation. This was followed by a multi-year large scale test in unit train service. An extensive investigation was made by CP into the steering characteristics and hunting stability of various new generation freight car trucks and CP also conducted a quantitative, comparative evaluation of the performance of conventional and radial freight car trucks, particularly with respect to wheel wear.

To complement the work done by the two railways, one research contract was awarded to each of Dynamic Sciences Ltd., (DSL) and the Canadian Institute of Guided Ground Transport (CIGGT). In the DSL work the capability of a Canadian-developed steady-state mathematical freight car curving model to predict freight car truck curving performance was evaluated. The CIGGT work consisted of an extensive computer analysis of rail wear and other operating costs resulting from freight car operation with the objective of determining the reductions in such costs which would result from the use of improved freight car truck designs in place of the conventional three-piece truck.

3.3 Track

Work on this component of the physical sub-system also constituted a major portion of the total program. It comprised 18 of the 44 basic tasks and included all major elements of the track system - rail, ties, ballast and sub-grade. Essentially, the work was directed to the development of ways and means to improve the capability of the track structure to safely and economically handle the rapidly growing number

of 100-ton cars being operated on each railway.

The initial CN work consisted of the design and construction of a fixed track structures test facility in order to provide improved ability to conduct track structure and track component research. This facility was utilized by CN for accomplishment of several of the early research tasks including investigations of the holding power of various rail tie-down systems, investigations into methods for measuring track modulus and some of the early work related to improved concrete track tie design.

Extensive investigations into the causes of rail corrugations and studies of the wear and fatigue characteristics of rail were conducted by CP researchers. Field investigations were made by both groups of researchers into the benefits (reduced wear) to be derived from the use of premium (alloy) rail steels in curves, and into the extension of rail life in curves through rail lubrication. New rail profilometers were developed.

A major project was carried out by CP involving the design of a Chromium-Molybdenum alloy rail steel, the production of experimental heats of the new steel (in conjunction with Algoma Steel and others) and its laboratory and in-track testing.

Commencing with laboratory and field testing of existing concrete ties, CN developed an improved concrete track tie design and carried the development through to the point where more than 500,000 of the improved ties are now in track. Further potential for stronger and longer lasting track was developed through an extensive ballast and subgrade research and testing program.

3.4 Bridges

All of the work on this sub-component of the physical sub-system was carried out by CP, and consisted of field investigations of the effects of train passage on bridges - both superstructure and substructure. The work provided information to enable more accurate design and analysis with resultant increased safety and reduced maintenance costs.

3.5 Vehicle and Train Dynamics

Work on the vibrational characteristics of freight cars and on the dynamic effects of unsprung weight on track loadings was carried out by CP. Methodology for instrumenting freight car and locomotive wheelsets, and, as well, two instrumented freight car wheelsets were developed by CN. All of this work contributed significantly toward a better research capability in this important component of the physical sub-system of railways.

3.6 Rail/Wheel Interface

Working in conjunction with CP, an experimental apparatus to enable the carrying out of a wide variety of laboratory rail/wheel wear tests was designed, tested and made operational by personnel of the Vancouver Western Laboratory of the National Research Council of Canada (NRC). Subsequently, the apparatus was further enhanced and valuable use of it is being made in the current NRC/TDC/AAR research program aimed at developing a fatigue and wear model for railway rail. CP also conducted analytical studies of steady-state curving and dynamic behaviour of the wheel/rail system, including the development of related computer programs. That work, which is continuing, is leading to an improved understanding of the complex and important subject of wheel/rail contact mechanics.

4. TASK SUMMARIES

For each of the 44 basic tasks, the task activities were synthesized, technical reports and published papers on the work listed, and results/findings of the work summarized.

As was noted in Section 3, a list of the basic tasks, grouped by component/sub-component of the physical sub-system, is provided in Table 2.

The task summarizations, in the format outlined above, and in the same sequence as the listing in Table 2, follow Table 2.

It will be observed that in the interest of brevity, the synopses of task activities usually include no mention of the work of data analysis and report preparation, notwithstanding that these activities were in fact a part of most tasks. In total, there were more than 100 technical reports prepared. Generally, the summaries of results/findings were derived from a review of the technical reports prepared on the work done. For a few of the tasks, particularly those for which no reports were prepared, the results/findings were derived from analysis of the work done as reported in the task progress reports provided to TDC by the performing organization.

Table 2

Basic Tasks - Canadian Track/Train Dynamics Research Program

<u>Task Number and Title</u>	<u>Page Number</u>
<u>Locomotive Trucks</u>	14
1. Investigate methods to improve the curve negotiation characteristics of 3-axle locomotive trucks (CN)	14
2. Investigate the curving performance of 3-axle locomotive trucks (CP)	16
<u>Freight Car Trucks and Wheels</u>	19
3. Develop testing techniques to measure freight car truck characteristics (CN)	19
4. Develop and test an experimental side frame stabilizer and hydraulically activated inter-bogie coupling equipment (CP)	21
5. Carry out theoretical computer work on the stability and curving of freight car trucks (CN)	23
6. Conduct tests to determine the effects of wheel profile on vehicle tracking and stability and wheel wear (CN)	24
7. Conduct engineering studies of vehicle tracking behaviour on curves (CN)	26
8. Evaluate the comparative wear characteristics of an experimental worn freight car wheel profile against the AAR wheel profile (CP)	27
9. Develop techniques and instrumentation to accurately measure wheelset angle-of-attack using laser equipment (CP)	29
10. Conduct wheelset angle-of-attack measurements on regular train consists (CP)	30

Table 2 (cont'd)

<u>Task Number and Title</u>	<u>Page Number</u>
11. Develop a retrofit for freight car trucks to provide articulation capability (CN)	31
12. Acquisition and evaluation of articulated trucks (retrofitted 3-piece) on a large scale in unit train service (CN)	35
13. Investigate the steering characteristics and hunting stability of various "new generation" freight car trucks (CP)	38
14. Obtain quantitative data on the performance of conventional and radial freight car trucks, particularly with respect to wheel wear (CP)	41
15. Establish the capability of a Canadian-developed steady-state mathematical freight car truck curving model to predict freight car truck curving performance (DSL)	43
16. Evaluate and compare, by computer analysis, the reduction in rail wear and other railway operating cost components expected to result from the use of improved freight car truck designs (Type II) in place of the conventional three-piece truck (Type I) (CIGGT)	45
17. Design and develop a wheel profilometer (CP)	46
18. Conduct a study of crack initiation in 100-ton coal car truck bolsters (CP)	47
<u>Track</u>	49
19. Design and construct a fixed track structures test facility (CN)	49
20. Conduct rail jacking tests to investigate the holding power of various rail tie-down systems (CN)	50
21. Develop a simpler technique for measuring track modulus (CN)	52
22. Investigate the phenomenon of rail corrugations (CP)	54
23. Investigate the nature and magnitude of rail wear under heavy traffic conditions (CP)	56

Table 2 (cont'd)

<u>Task Number and Title</u>	<u>Page Number</u>
24. Study the wear and fatigue characteristics of rail steel (CP)	58
25. Develop a new rail curve grease to reduce wear (CP)	60
26. Monitor, in the field, rates of wear on curves with premium rail steels and rail lubrication (CN)	62
27. The production of experimental heats of Chromium-Molybdenum alloy rail steel, and the rolling and testing of rail from these heats (CP)	63
28. Collect and compare data on wear of fully heat-treated Russian P-65 rail and Algoma 1% Chromium rail (CP)	66
29. Develop a non-destructive method for determining the thermal stress in long welded rails (CWR) at any time during their life in track (CN)	68
30. Develop a satisfactory method for bringing strings of continuous welded rail (CWR) to the preferred laying temperature, by heating ahead of laying when using the Rail Change Out Machine (RCO) (CN)	70
31. Design and develop a rail profilometer (CN)	72
32. Design and develop a rail profilometer (CP)	73
33. Conduct research on the design and performance of concrete track ties and fastenings (CN)	74
34. Conduct studies related to the properties of ballast and the strength and stability of the ballast system (CN)	82
35. Develop a machine to mechanize trowelling operations (CN)	85
36. Conduct laboratory and field investigations of subgrade soils to enable accurate predictions of optimum subballast thickness requirements (CN)	86
37. Conduct investigations on the alleviation of frost heaving of railway track roadbed by chemical treatment (CN)	88

Table 2 (cont'd)

<u>Task Number and Title</u>	<u>Page Number</u>
<u>Bridges</u>	91
38. Investigate the effects of train passage on the super-structure and substructure of bridges (CP)	91
<u>Vehicle and Train Dynamics</u>	93
39. Investigate the vibrational characteristics of freight cars (CP)	93
40. Investigate the dynamic effects of unsprung weight on track loadings (CP)	94
41. Develop instrumented freight car and locomotive wheelsets (CN)	96
42. Develop a train handling recorder (CN)	98
<u>Rail/Wheel Interface</u>	100
43. Develop experimental rail/wheel wear apparatus (CP)	100
44. Conduct analytical studies of steady state curving and dynamic behaviour of wheel/rail systems (CP)	101

4.1 Locomotive Trucks

Task 1 - Investigate methods to improve the curve negotiation characteristics of 3-axle locomotive trucks.

Performing Organization - CN Rail Research

TTD Contract Phase - I, II, III

Synopsis of task Activities

Phase I

- . Consideration was given to use of an interbogie connector for 6-axle (SD-40) locomotives in order to reduce the lateral forces introduced into the track during curve negotiation and which on CN had necessitated the application of a slow order on curves over 4 degrees for these units. However, before entering too extensively into the application of interbogie connectors for locomotive trucks, it was decided to investigate the possibility of improving the stability and curving characteristics of 6-axle locomotives by the introduction of increased lateral clearance in the centre axle of the three axle trucks on these units, as it was apparent that such a modification, if successful, could be more economic than complex interbogie connectors required for North American design locomotives.
- . In this connection, strain search tests were carried out on a General Motors Hyatt bearing thrust cap in order to produce an axle force thrust transducer. The technique appeared suitable and the centre axle assembly of a GMSD-40 locomotive was modified to increase the lateral axle clearance by a full 1/2".
- . Using modified bearing caps, tests to evaluate the effects of the truck modification were made on the test track. Results justified road testing.
- . Road tests were run both with and without the axle modification. Results showed a reduction of 15% - 20% in the leading axle lateral thrust load with the modified truck.

Phase II

- . A comprehensive computer program was developed to study the quasi-steady lateral curving forces of locomotive trucks. Simulations were carried out on the 3-axle SD-40 truck to evaluate possible truck modifications which would effect a reduction in lateral curving forces. These included extra centre axle clearance, increased longitudinal axle/pedestal clearances and higher conicity wheel profile. (CN modified Heumann profile).

- . Various conditions of curvature, speed, superelevation and truck modification were simulated. The best performance was obtained by combining all three modifications.
- . The decision was taken to apply the three modifications to all existing CN 6-axle locomotives of the GF-30 class. (SD-40)

Phase III

- . The first modified 6-axle GF-30 locomotive was released from CN Shops in May, 1976. The changes made to the modified unit were as follows:
 - (1) Modified wide flange Heumann wheel contours instead of the AAR 1/20 taper contour.
 - (2) Extra center axle lateral clearance of 1" added (total lateral of 1-7/16").
 - (3) Extra longitudinal pedestal clearance of 1/8" added to all journal positions. (The new total longitudinal pedestal clearance was 1/4" and the condemning limit 3/8".)
- . A test program was set up to evaluate and confirm the improved curving performance of a modified unit.
- . Three comparison locomotives were selected for testing with the modified GF-30 locomotive. They were a standard GF-30 (equipped with new AAR 1/20 taper wheels, 7/16" center axle lateral clearance, 1/8" longitudinal pedestal clearance); a 4-axle GF-430 locomotive with AAR 1/20 taper wheels and new truck clearances; and an MF-30 6-axle unit on modified Heumann contour wheels, but otherwise, as to new builder's standard.
- . Twelve strain gauged Hyatt roller bearing thrust caps and four dynamometer track base plates (to measure vertical and lateral tie plate force) were repaired and recalibrated for these tests. Two test curves in Montreal Yard were set up to evaluate the base curving forces of the test locomotives. The curves were regauged, aligned and surfaced to standard new condition in order to compare measured lateral base curving forces (without significant dynamic effects) with computer predictions on both a 5 degree and 12 degree curve. Road tests were then made with the standard and modified GF-30 units equipped with strain gauged bearing thrust caps on the trailing truck of each unit in order to evaluate the dynamic bearing thrust loads under operating conditions.
- . Based on a preliminary analysis of the test data, the computer predictions of reduced base curving forces on the modified unit were verified.

As well, a reduction of peak lateral dynamic bearing thrust loads was observed in the modified unit when compared to the standard unit in curved track.

Reports

No report was prepared on this work.

Results/Findings

- . It was decided to proceed with the modifications to all existing CN 6-axle locomotives of the GF-30 class and to remove the special curve speed restriction on all modified units.
- . A subsequent decision was made to specify these modifications on all new 6-axle EMD locomotives, and also to adopt the modified Heumann profile for MLW 6-axle locomotives.
- . As a result of the modifications, track damage and locomotive wheel wear was reduced and the safety and speed of train service improved, particularly in heavy curve territory.

Task 2 - Investigate the curving performance of 3-axle locomotive trucks.

Performing Organization - Department of Research, Canadian Pacific Limited, with participation by the Railway Laboratory of the National Research Council of Canada.

TTD Contract Phase - IV and V

Synopsis of Task Activities

Phase IV

- . Initial locomotive curving performance tests were made during the curving performance tests of the Railroad Dynamics Inc., (RDI) freight car trucks, conducted on the CP Laggan Subdivision (see task "Investigate the steering characteristics and hunting stability of various new generation freight car trucks - Phase IV"). The consist for those tests was powered by three General Motors SD-40-2 3000 HP locomotives and curving data were collected for the locomotives as well as for the freight cars. The test site was a 5 degree curve which was instrumented to measure lateral and vertical rail forces and the angle-of-attack of each wheelset as it passed the instrumented site. A total of 72 runs were made at speeds of 25,

37 and 45 mph on dry rail, with the locomotives coasting through the instrumented section of the curve.

Phase V

- . Subsequent tests were conducted at the same location on the Laggan subdivision to evaluate the comparative curving performance of three types of 3-axle locomotive trucks. The locomotive test consist was comprised of a General Motors SD-40-2 3000 HP unit, a General Motors SD-40 3000 HP unit and a Montreal Locomotive Works M636 3300 HP unit, each equipped with service worn wheels. Angle-of attack, lateral and vertical force data were collected for a total of 72 runs, at speeds of 25, 37 and 45 mph with the locomotive coasting through the instrumented section of the curve.
- . Through computer simulation studies (carried out by Dynamic Sciences Ltd. on behalf of CP - see DSL report of Sept. 1981 listed below), two areas for improvement in the high curvature curving performance of GM SD-40-2 3-axle trucks were identified. By increasing the conicity of AAR new wheel profiles, or by increasing the mid-axle lateral clearance, leading axle lateral forces on the high rail could be reduced. Plans were made to conduct field tests to validate the effects of such modifications, and at the same time, to investigate the effect of rail flange lubrication and wheel profile on curving performance.
- . The field tests were made on 2 degree, 4 degree and 8 degree curves on the CP Thompson Subdivision. Each curve was instrumented to measure lateral/vertical forces on both high and low rails and wheelset angle-of-attack at the same location. Two series of tests were conducted at the three test sites, the second series being conducted four weeks after the first during which interval the locomotives were returned to revenue service and the rail was newly ground to an experimental profile. Runs were made with rail dry and rail lubricated.
- . The locomotive test consist was comprised of 3-GM SD-40 locomotives always coupled in the same order. Mid-axle lateral clearance on the locomotives was increased by removing the inner strip on the mid-axle journal box in the pedestal area. Wheel profiles of the locomotives were taken and recorded during the first series of tests and repeated after the second. High and low rail profiles were taken before and after rail grinding.

Reports

"Curving Performance of SD-40-2 Locomotive Trucks", by W. Pak, Department of Research, Canadian Pacific Limited, June 1981.

CP Report No. - S677-81

TDC Report No. - TP3050

This report is also included as pages 169-195 of the Canadian Pacific final report on Phase IV, Track/Train Dynamics Volume 2, 1981", TDC Report No. TP3120 (no CP number).

"Curving Performance Test of GM SD-40, SD-40-2 and MLW M636 Locomotive Trucks", by W. Pak, R. Gonsalves and G. Izbinsky, Department of Research, Canadian Pacific Limited, April 1982
CP Report No. S715-82 TDC Report No. - TP3776E

This report is also included as pages 52-69 of the Canadian Pacific final report on Phase V, "Track/Train Dynamics Volume 3, 1982", TDC Report No. TP4183E (no CP number).

"Effect of Axle Lateral Clearance and Wheel Profile Variation on the Curving Performance of SD40-2 Locomotive Trucks", by W. Pak and R. Gonsalves, Department of Research, Canadian Pacific Limited.

This report was not published separately but is included as pages 70 - 112 of the Canadian Pacific final report on Phase V, "Track/Train Dynamics Volume 3, 1982", TDC Report No. TP4183E (no CP number).

"Technical Report Concerning Four Modifications to the SD40-2 Locomotive Trucks to Reduce Track Loadings in Curves and Improve Ride", by Dynamic Sciences Limited, September 1981.

Results/Findings

- . Preliminary data was obtained on the general curving performance of SD40-2 locomotive trucks (CP Report No. S677-81)
- . It was found that SD40 locomotive trucks generated a slightly higher angle-of-attack at the lead axle, and had a slightly larger weight transfer effect among the axles in the same truck than did the SD40-2 and the M636 locomotives when tested on a 5 degree curve. (Report No. - S715-82)
- . It was found that for a GM SD40-2 locomotive:
 - considerably larger lateral curving forces were generated with new AAR profile wheels during the initial wear-in period of wheel life, compared with service worn wheels.
 - lead axle lateral curving forces on locomotives with service worn wheels were not significantly reduced by providing additional lateral clearance on the mid-axle.
 - high rail flange lubrication in curves resulted in increases in both wheelset angle-of-attack and lateral flange forces. (Phase V Final Report pages 70 - 112)

4.2 Freight Car Trucks and Wheels

Task 3 - Develop testing techniques to measure freight car truck characteristics.

Performing Organization - CN Rail Research

TTD Contract Phase - I & II

Synopsis of Task Activities

Phase I

- . The design of previously developed instrumented base plates was updated. Transducers to measure angle-of-attack and shear strain gauges to measure vertical contact load on the rail were developed.
- . A 5° curve in Montreal Yard was assigned as a test track and instrumented with base plates, angle of attack transducers and shear strain gauges.
- . A large number of tests and measurements of lateral and vertical forces resulting from freight car operation were carried out on the test track. These included comparative tests of a loaded 100-ton hopper car equipped with the following wheel profiles:
 - standard AAR 1:20 profile
 - modified Heumann profile designed by CN to give single point contact on new 132-lb. R.E. Rail.
 - profile A, being a new profile based on what was a best estimate of typical worn profiles in the running zone of the tread.
 - service worn profile as existing on test car CN 373048.
- . Two CP coal gondola cars equipped with hydraulic interbogie connectors were also tested.
- . An operational test was set up in Western Canada to measure lateral curving forces under unit train operating conditions. Two test sites were selected on the CN mainline, both on nominal 7° curves where excessive rates of rail gauge face wear had been observed. The test sites were instrumented using three force measuring base plates, rail shear gauges to measure vertical wheel load on high and low rails, and rail head lateral displacement transducers to measure track gauge widening. Data was recorded at each site for approximately one week on a 24-hour basis.

Phase II

- . Preliminary study was made of the vertical impact loading at rail joints from high speed passenger equipment aimed at evaluation of the effects of suspension design and unsprung mass. Development of an improved base plate was commenced and an experimental plate was built and tested. This development was subsequently terminated because

theoretical calculations were found to be adequate.

- . Improved techniques for measuring vertical contact load and lateral load on rail were developed as well as design and fabrication of fixtures for these purposes.

Reports

"Test Report on the Comparative Curving Performance of Freight Car Trucks on Special Wheel Profiles", by P. Marcotte, CN Rail Research, March 1975.

CN Report No. 122

TDC Report No. - None assigned.

"Tests on BC South Line Clearwater Subdivision", by F. E. King, CN Rail Research, Feb. 28, 1975.

CN Report No. - 124

TDC Report No. - None assigned.

Results/Findings

- . Significant advances were made in the development of instrumented base plates and other devices for measuring rail forces generated by rail vehicles.
- . The comparative test measurements on the 5 degree test curve demonstrated that:
 - wheel profile has a large influence on curving forces
 - the standard AAR profile in new condition is undesirable with respect to curving forces, wheel/rail contact stresses and wear.
 - the AAR profile in worn condition is also undesirable with respect to flange geometry, flangeway clearance and rail wear.
 - a new optimized hollow tread profile would offer:
 - reduced wheel and rail wear
 - reduced wheel/rail contact stresses
 - reduced lateral forces on truck structure
 - better centering action on straight track and expected reduction in rolling resistance.
- . The tests and investigations on Western Canada trackage confirmed that the damage occurring to the rail in curves was attributable to the use of heavily loaded 100-ton vehicles. It was concluded that the following remedial action should be taken:
 - remove the reverse curvature on worn wheel treads in order to reduce or eliminate the head flow and corrugation on the low rail.

- purchase new wheels with Heumann or other special wheel tread profiles in order to increase the curving ability of the wheelsets thereby reducing gauge face wear on the high rail and lessening the severity of head flow and rail corrugation on the low rail.
- maintain close control of track gauge in curves in order to reduce or eliminate rail head flow and corrugation on the low rail and reduce the gauge face wear on the high rail.
- maintain the existing rail gauge face lubricators in good operating condition and install additional lubricators where necessary, in order to reduce rail gauge face wear as well as wheel flange wear.
- use special high strength rail steel in curves wherever necessary.
- utilize a freight car truck with improved curving capability.
- maintain better control of wheelset diameter matching.
- adopt closer dimensional tolerances for axle spacing on truck side frames and truck pedestal side frame clearances.

Task 4 - Develop and test an experimental side frame stabilizer and hydraulically activated interbogie coupling equipment.

Performing Organization - Department of Research, Canadian Pacific Limited with participation by the Division of Mechanical Engineering of the National Research Council of Canada and CN Rail Research.

TTD Contract Phase - I

Synopsis of Task Activities

- . Two CP 100-ton bath-tub coal cars were equipped with side frame stabilizers and interbogie connection hardware at the CP Ogden Shops, Calgary, Alta. The hydraulic interbogie coupling hardware was a Swiss design intended to connect two rigid trucks on the same car in a manner that enables them to align themselves more effectively on a curve, thereby reducing wheel wear. Inasmuch as it was intended for use with rigid trucks, and the trucks on the CP cars were 3-piece type, an attempt was made to improve their rigidity by the addition of welded plates (side frame stabilizers) to reduce parallelograming. One car was equipped with a "saddle plate" design stabilizer, and the other with a "gusset plate" design stabilizer.

- . A detailed test plan was developed in conjunction with CN Rail Research for testing on a 5 degree curve on the test track at Montreal Yard utilizing the CN instrumented base plates to measure lateral curving forces.
- . Functional testing of both cars, in light condition, was carried out at Ogden Yard and for high speed stability using video equipment on the main line. The cars were loaded and moved in revenue service to Montreal.
- . The two cars were tested on the CN test track at Montreal with the cars equipped with new wheels and also with worn profile wheels. Tests were conducted with the hydraulic interbogie coupling systems in both the operational and inactive state and with the side frame stabilizers disconnected.
- . Pressure transducers were connected to the hydraulic system on one of the cars to determine if there was a hydraulic pressure differential build-up during curve negotiation. Strain gauging was applied to the mechanical linkages of the interconnector to determine whether force levels during curve negotiation were of sufficient magnitude to result in failure of the connecting rod.
- . A test run of the instrumented car was made to determine hydraulic pressure and forces in the mechanical linkages during curve negotiation.

Reports

"Track/Train Dynamics Report #3 - Testing of 100-ton Bathtub Coal Cars Equipped with Hydraulic Interbogie Coupling Devices, April 30 - May 14, 1974", by R. Gonsalves, Department of Research, Canadian Pacific Limited, October 1974.

CP Report No. - S485-74

TDC Report No. - None assigned

This report is also included as Section C of the Canadian Pacific final report on Phase I "Track/Train Dynamics Phase I", March 1975.

CP Report No. - None assigned

TDC Report No. - None assigned

"Track/Train Dynamics Report #3A, Test on 100-Ton Bathtub Coal Car Equipped with Hydraulic Interbogie Coupling and Sideframe Stabilizers on November 28, 1974", by R. Gonsalves, Department of Research, Canadian Pacific Limited, March 1975.

CP Report No. S492-75

TDC Report No. - None assigned

Results/Findings

- . The test data revealed that the interbogie device was apparently ineffective in reducing lateral curving loads as measured by the baseplates. Curving loads with profiled worn wheels were found to be lower than with new AAR Contoured wheels.
(Report No. - S485-74)

- The test data indicated that the hydraulic system was active when the car was negotiating a curve and that the tensile stress in the connecting rod was well within acceptable design limits.
(Report No. - S492-75)

Performing Organization - CN Rail Research

Synopsis of Task Activities

Reports

Results/Findings

- . A theory was developed to explain how unsymmetrical truck characteristics could generate a process of accelerated wheel wear and how a different initial wheel profile could alleviate the situation.
- . Two possible designs of profiled wheels were examined and their characteristics studied.
- . It was concluded that the use of profiled wheels on freight cars would produce savings resulting from
 - reduced wheel and rail wear
 - reduced curve negotiation forces on track structures and
 - reduced rolling resistance in curves.

Task 6 - Conduct tests to determine the effects of wheel profile on vehicle tracking and stability and wheel wear.

Performing Organization - CN Rail Research

TTD Contract Phase - I, II and III

Synopsis of Task Activities

Phase I

- . Design of an accurate profiling jig referring wheelset profile geometry to axle centre line was carried out, but the jig was not built.
- . A considerable number of wheel profile measurements were made using existing gauges and by other methods and with these data, an attempt was made using numerical analysis techniques, to define the radii of curvatures. This proved unsuccessful.

Phase II

- . Tracking stability tests were carried out on empty 100-ton tank hopper car equipped with profile A and modified Heumann profile wheels. (both representing a service-worn profile)
- . A wheel profilometer was developed and tested as well as software for processing measurements.
- . An optical system was developed for measurement of the angle of attack of rail vehicle wheelsets to the track in curves.
- . A survey of service-worn wheel contours was carried out at Port Mann Yard on 100-ton capacity cars in unit train service to determine the

frequency of occurrence and severity of convex tread curvature on the wheel tread near the front edge of the tread.

- . Planning for a comparative wheel profile service test was completed, methodology developed for production of accurately profiled wheels and the wheels produced. The profile selected for testing was Profile A.
- . 51 carsets were made up with wheel profiles as follows and installed under CN coal gondola cars of the CN 199000 series:

Standard AAR	- Wide Flange	- (17 carsets)
Experimental Profile A	- Wide Flange	- (25 carsets)
Standard AAR	- Narrow Flange	- (4 carsets)
Experimental Profile A	- Narrow Flange	- (5 carsets)

- . All cars except one equipped with profile A wide flange wheels, one with profile A narrow flange wheels and one with standard AAR wide flange wheels were returned to coal service.
- . Comparative hunting tests were conducted in a train consisting of the three cars held out and one other gondola car of the same series - with AAR service-worn wheels selected at random from service. The cars were then returned to coal service.

Phase III

- . Precision wear measurements (using the precision wheel profilometer) were taken on one car equipped with AAR wide flange wheels and one equipped with profile A wide flange wheels at 1500, 4800, 9300, 17000 and 39,500 miles. (The same two cars were measured each time)
- . The remaining test cars were monitored at intervals using a pencil tracing type profilometer to give statistical confidence in the comparative test results.

Reports

"Wheel Profile Test on Luscar CN 199000 Series Coal Gondolas - Hunting Tests November 1975" by W. N. Caldwell and J. L. Bousquet, CN Rail Research, April, 1976.

CN Report No. - M126

TDC Report No. - None assigned

"Wheel Profile Test on Luscar Coal Service Gondolas - Progress Report #1", by P. Marcotte and R. Mathewson, CN Rail Research, March 18, 1976.

CN Report No. - M125

TDC Report No. - None assigned

"Wheel Profile Service Test Luscar Coal Service Gondolas, Wheel Wear Measurements - Progress Report #2", by W. N. Caldwell, P. Marcotte, R. Mathewson, CN Rail Research, June 14, 1976.

CN Report No. - M128

TDC Report No. - None assigned

"Wheel Profile Test - Luscar Coal Service Gondola, Wheel Wear Measurements (39,500 miles) - Progress Report #3", by P. Marcotte and K.J.R. Mathewson, CN Rail Research, January, 1977.

CN Report No. - M132

TDC Report No. - None assigned

Results/Findings

- . A precision wheel profilometer was developed (CN Report No. M125).
- . From the hunting tests it was determined that the dynamic tracking properties of the Profile A wide flange contour wheels are similar to those obtained with AAR service - worn contours (CN Report No. M126).
- . The wear measurements showed much less wear on the profile A wheels than on the AAR profile wheels - both tread and flange. On the basis of the measurements taken at 39,500 miles, the projected average profile A wheel life to first turning was 1.79 times that of the AAR profile wheel life. (CN Reports No. M125, M128 and M132)

Note: For 36" diam. wheels in 100-ton car service, CN adopted the modified Heumann (worn wheel) profile.

Task 7 - Conduct engineering studies of vehicle tracking behaviour on curves.

Performing Organization - CN Rail Research

TTD Contract Phase - IV

Synopsis of Task Activities

- . The purpose of this work was to evaluate, theoretically, the lateral wheel/rail forces generated by freight car trucks in curved track under service conditions of buff or draw loads in train. Data were developed for computer analysis of loaded coal gondolas under buff and empty coal gondolas under draw coupler loading in curved track. Software was developed to generate the lateral component of truck center plate force under conditions of coupler longitudinal loading and angularity.
- . Computer runs were made to develop the following data on wheel/rail forces for two coupled coal gondola cars:
 - (1) wheel/rail net lateral forces (outer wheel of leading axles, both trucks)
 - (2) wheel/rail L/V ratios (outer wheel of leading axles, both trucks)

for buff and draw loads in 50 kip increments from minus 250 kips to plus 350 kips and for track curvature to 10 degrees. The computer data were plotted.

Reports

No final report was prepared on this work. However, the work is described and discussed in CN Report 140 "Locotrol Test Winniandy to Jasper October 1976 - February 1977" pp 19 - 29.

Results/Findings

An improved understanding was gained of the cause and magnitude of lateral wheel/rail forces generated by freight car trucks in curved track under severe conditions of buff or draw. It was concluded that the use of remote power in heavy trains would not lead to a reduction in rail wear in curves.

Task 8 - Evaluate the comparative wear characteristics of an experiments¹ worn freight car wheel profile against the AAR wheel profile.

Performing Organization - Department of Research, Canadian Pacific Limited.

TTD Contract Phase - III, IV and V

Synopsis of Task Activities

- . Four 100-ton coal cars were designated as test cars and fitted with wheels and other features as follows:
 - Car 1 - CN "A" profile wheels, brake connected.
 - Car 2 - CN "A" profile wheels, brake cut out.
 - Car 3 - "AAR" profile wheels, brake connected
 - Car 4 - CN "A" profile wheels, brake connected and centre plate extension pad (C-PEP) added.
- . All cars were equipped with Barber S2-C trucks. All wheels were two wear 36 inch diameter Class C wide flange wrought steel. All cars had CP standard WABCO PAC brakes except Car 2.
- . The test cars were placed in unit train service operating between coal mines at Kaiser or Fording and Vancouver, B.C.
- . Profile measurements of the wheels were taken at 1,720, 3,180, 8,750, 44,470, 67,000, 94,000 and 203,000 miles. All wheel profile

measurements except the final set were taken using the CP Research Department's original profilometer which is an electro-mechanical device which collects and stores measured wheel profile digital data. The data were computer processed and plotted and wear data were obtained by graphical matching. The last set of wheel profile measurements were made with the new CP "floating concept" profilometer. (See task "Design and develop a wheel profilometer"). Although this profilometer is capable of processing wear data automatically through the computer, it was not possible to do so because of the unavailability of initial wheel profiles in a format suitable for acceptance to the computer software of the new profilometer. To calculate flange wear and tread wear data, use was made of available normal 'AAR' and 'A' profile data.

- . A number of wheelsets were changed during the test period due to shelling.

Reports

"Experimental and AAR Wheel Profile Measurements on a CP Unit Coal Train - Interim Report", by G. Izbinsky and W. Pak, Department of Research, Canadian Pacific Limited, July 1980.

CP Report No. - S-644-80

TDC Report No. - TP2728

This report is also included as pages 69-114 of the Canadian Pacific final report on Phase IV, "Track/Train Dynamics Volume 2, 1981", TDC Report No. - TP3120 (no CP number).

"Experimental 'A' and 'AAR' Wheel Profile Measurements on a CP Unit Coal Train - Final Report", by V. Katchadourian, Department of Research, Canadian Pacific Limited, November 1983.

CP Report No. - S790-83

TDC Report No. - TP5081E

Results/Findings

- . Flange wear data indicated that the wear of 'AAR' profile wheels was higher than that of the 'A' profile wheels. The wear rate was higher to approximately 44,000 miles after which both 'A' and 'AAR' profile wheel flange wear rates became similar.
- . Tread wear data showed that the 'AAR' profile wheel had greater tread wear than the 'A' profile both in the initial 'break-in' period and during subsequent service.
- . Both 'A' and 'AAR' profile wheels attained a common worn profile, but the 'A' profile wheel stabilized faster in the flange throat region.
- . Based on a single point measurement, the car with inoperative brakes experienced more tread wear as compared to the car which operated with normal brakes. As tread wear measurements were taken at one point

2 7/8" from the back face of wheels, no definitive conclusion could be made concerning the effect of braking on tread area wear.

- . It was observed that brakes assist wheels to develop a more even tread wear pattern.

Task 9 - Develop techniques and instrumentation to accurately measure wheelset angle-of-attack using laser equipment.

Performing Organization - Department of Research, Canadian Pacific Limited with participation by personnel of the Instrument Section, Division of Mechanical Engineering of the National Research Council of Canada and by CN Rail Research.

TTD Contract Phase - II

Synopsis of Task Activities

- . Optical equipment for the task was purchased and mechanical accessories assembled.
- . A preliminary test to measure angle-of-attack using the electro-optical equipment was made.
- . The equipment was further tested at the CN Rail Montreal Yard in conjunction with curving performance tests carried out by the CN Technical Research staff.

Reports

"Measurement of Angle-of-Attack With Lasers", by J. Kalousek and L. M. Yee, Department of Research, Canadian Pacific Limited, September, 1977.
CP Report No. - S552-77 TDC Report No. - TP1225

This report is also included as pages 157-183 of the Canadian Pacific final report on Phase II, "Track/Train Dynamics Volume 1, 1978", Report No. - TP4576E (no CP number).

Results/Findings

A method of measuring the angle-of-attack of a wheel flange of a rail vehicle to the rail was developed. The system will be particularly useful in research work concerned with the steering of railway car trucks around curves. Potential improvements to the system were identified.

Task 10 - Conduct wheelset angle-of-attack measurements on regular train consists.

Performing Organization - Department of Research, Canadian Pacific Limited.

TTD Contract Phase - V

Synopsis of Task Activities

- . The CP laser angle-of-attack equipment (See task "Develop techniques and instrumentation to accurately measure wheelset angle-of-attack using laser equipment), was installed on an 11 degree curve at mileage 98.6 of the CP Mountain Subdivision, to capture the "steady-state" curving performance of freight car trucks.
- . Wheelset angle-of-attack measurements were made on a total of six trains, both eastbound and westbound.

Reports

"Wheelset Angle-of-Attack Measurement of Regular Train Consists", by W. Pak, G. Izbinsky and H. Soares, Department of Research, Canadian Pacific Limited.

This report was not published separately but is included as pages 113-123 of the Canadian Pacific final report on Phase V, "Track/Train Dynamics Volume 3, 1982", TDC Report No. - TP4183E (no CP number).

Results/Findings

- . It was found from analysis of the data obtained that individual trucks which parallelogram excessively, and also "stuck trucks", could be readily identified.
- . From this, it was concluded that it would be possible to obtain a complete data file of angle-of-attack profile together with curving force distribution for each individual locomotive truck and trucks for all unit coal cars at a convenient location on medium and high curvature tracks. This would have the benefit that once initiated, such a data file could be updated periodically to isolate trucks with less desirable curving performance and to compare individual truck performance before and after scheduled maintenance.

Task 11 - Develop a retrofit for freight car trucks to provide self-steering capability.

Performing Organization - CN Rail Research with participation by Railway Engineering Associates Inc.

TTD Contract Phase - I, II, III and IV

Synopsis of Task Activities

Phase I

- . In accordance with a previous agreement between CN and Railway Engineering Associates, two prototype articulated trucks were delivered to CN. Modifications were made to a 100-ton open top hopper car to accept the new trucks and the trucks installed.

Phase II

- . Studies were made of the influence of 100-ton cars on operating costs for CN's B.C. South Line. Past and present costs for rail replacement, tie replacement, other track maintenance and train accidents were analyzed.
- . Evaluation and testing was carried out on the empty experimental car. The initial work consisted of:
 - Dynamic shake tests to determine car body/suspension natural frequencies and damping.
 - Radial alignment characteristics of the truck axles in running tests on curved track.
 - High speed hunting stability on Profile A (worn contour) wheels. (The car was found to be stable at speeds up to 78 mph).
- . Loaded car tests on mainline track were carried out at speeds up to 70 mph. Tracking characteristics at high speed were satisfactory but improvements in secondary suspension lateral damping for low speed operation appeared necessary. Curve negotiation performance was satisfactory.
- . Comparative curving tests were carried out on the 5° test track curve in Montreal Yard with a car equipped with standard three-piece trucks and AAR 1:20 wheel profiles. The articulated trucks on the experimental car were fitted with Profile "A" wheels. Measurements were made of vertical and lateral wheel/rail contact loads, vertical/lateral rail/tie

reaction force and angle-of-attack. Analysis of data showed a reduction in 56% in lateral tie plate force and of 71% in angle-of-attack for the articulated truck compared to the standard truck.

- . Test results were encouraging but for reasons of compatability with standard trucks and cost, a redesign of the articulation concept based on the retrofitting of steering components into existing 100-ton freight car trucks was undertaken by Railway Engineering Associates at the request of CN.
- . A carset of three-piece 100-ton capacity freight car trucks was received from Dofasco/National Steel Car Corporation after having an experimental set of articulation frames applied to these trucks as a retrofit assembly.

Phase III

- . After lab. testing and modification of the steering assembly, the retrofit trucks were mounted under a 100-ton capacity open top hopper car. High speed hunting tests of the empty car were made with Profile A wheels. The trucks were stable up to 70 mph. Comparative tests were made with the hopper car on standard trucks with slightly worn wheels. The trucks in this case were stable up to only 50 mph.
- . Further hunting tests were carried out with the retrofit articulated trucks mounted under an empty 100-ton capacity hi-cube box car.
- . A video film was produced, with clips of the retrofit truck under high-speed test conditions
- . Comparative curving tests under two loaded 100-ton hopper cars were carried out on the 5 degree and 12 degree test curves in Montreal Yard. Track base plates were installed on the high rail of both curves to measure comparative lateral curving forces of the test trucks. An optical system for wheelset angle of attack measurement developed by CP Rail Research and NRC was installed on the 5 degree curve.
- . The articulated retrofit trucks fitted with Profile A wheel contours were installed under one test car. Standard 100-ton three-piece freight trucks with new AAR contour wheels were used on the other reference car. Test data were taken under dry and lubricated rail conditions.
- . Following yard tests, a road test was made on the Lac St. Jean Subdivision to measure steering characteristics (i.e., wheelbase variation) of the loaded car under service operating conditions in a range of track curvatures from 0 degrees to 10 degrees. As well, high speed (60 mph) operation of the loaded car was observed and the ride was monitored. Test data on interaxle steering forces was measured for design purposes.
- . Data from tests were analyzed.

- . Stress analysis was carried out on a prototype production set of retrofit steering arms.

Phase IV

- . Design calculations pertaining to the production castings for the steering arms of the retrofit articulated truck were carried out. Discussions were held in Hamilton with Dresser Industries and Dofasco regarding design improvements. Characteristic tests were carried out on elastomeric components to be incorporated in the design.
- . Economic analysis of the potential savings which could be achieved with the articulated truck were carried out, including fuel savings due to reduced curving resistance, based on the use of the CN Transportation Department's Train Performance Calculation Program.
- . Preparation of test rig and equipment for static and dynamic lateral suspension tests was carried out pending delivery of one carset of cast steering arms and associated elastometers to CN Rail Research.
- . Two production articulated trucks were assembled and inspected at Dofasco in Hamilton, and then shipped to CN Rail Research in Montreal. Two 100-ton capacity coal gondola cars were called to Montreal from Western Canada for use as test cars in the upcoming road test series.
- . Dynamic suspension tests using a special hydraulic actuated rocker rig were carried out to determine the suspension stiffness characteristics of the articulated truck. One cast steering arm was extensively strain gauged and calibrated to monitor operating forces on this component during service testing.
- . Hunting tests were conducted on two empty coal gondola cars, one equipped with standard trucks on service worn wheels (54,000 mi service), and the other equipped with articulated trucks and simulated service worn wheels (Profile A). The standard car exhibited violent hunting oscillations above 54 mph. The car equipped with articulated trucks was stable at 80 mph (the design target) and run under test conditions up to 92 mph.
- . The cars were then loaded to capacity (263,000 lb. on rail) and four test runs were made on the Lac St. Jean Subdivision between Hervey Junction and Riviere a Pierre where there are 80 curves up to 10° curvature in this 22-mile section. Truck wheel base change in curved track and steering forces were measured.
- . Comparative curving force tests were carried out on 5 degree and 12 degree test curves in Montreal Yard. The curves were instrumented with dynamometer tie plates and an optical device for measurement of wheel-set angle-of-attack. Comparative curving performance data were taken under loaded cars for both the standard and retrofit trucks.

- . A test rig for carrying out accelerated endurance testing of the steering components was developed.
- . Data analysis was completed on the curving performance of the 100-ton capacity cast steel production articulated truck. Curving forces were reduced by 60% and angle-of-attack reduced by 80% for the 5 degree test curve.
- . Accelerated fatigue testing was performed on the steering components based on a service loading spectrum measured in field tests. These tests resulted in minor casting design improvements which were incorporated in the ten carsets being produced for CN service testing in unit coal train service.

Note: This work was continued by CN Rail under cooperative Contract OSD79-00040 with TDC, "Acquisition and Evaluation of Articulated Trucks on a Large Scale in Unit Train Service".

Reports and Published Papers

- "Rail Replacement Costs on the B. C. South Line" by F. E. King, CN Rail Research, May 1976.
CN Report No. - 147 TDC Report No. - none assigned.
- "Effect of 100-ton Carloadings on Train Accident Costs - B. C. South Line" by F. E. King and C. J. Dalton, CN Rail Research, June 1976.
CN Report No. 143 TDC Report No. - None assigned.
- "Effect of 100-ton Carloadings on Tie Replacement Costs - B. C. South Line" by F. E. King, CN Rail Research, May 1977.
CN Report No. - 150 TDC Report No. - none assigned.
- "Track Maintenance Cost, B. C. South Line, 1964 - 1974 inclusive - Summary Report" by F. E. King and C. J. Dalton, CN Rail Research, September 1977.
CN Report No. 144 TDC Report No. TP1222.
- "Articulated Truck Development" by P. Marcotte and W. N. Caldwell, CN Rail Research, June 3, 1977.
CN Report No. 136 TDC Report No. - TP1221.
- "Performance Analysis and Testing of a Conventional Three-Piece Freight Car Truck Retrofitted to Provide Axle Steering", by P. Marcotte and W. N. Caldwell, CN Rail Research, and H. A. List, Railway Engineering Associates Inc., November 1978.
CN Report No. - 154 TDC Report No. - TP1988.
- "Development and Testing of DR-1 Self-Steering Freight Car Truck" by W. N. Caldwell, CN Rail Research, and D. W. Dibble, Transport Canada Research and Development Centre. Proceedings of the 5th Symposium on Engineering Application of Mechanics, Research Council of Canada, Ottawa, June 1981.

Results/Findings

- . The studies made of the influence of 100-ton cars on operating costs on the B. C. South Line verified the strongly suspected dramatic increase in these costs resulting from the introduction of unit trains comprised of 100-ton cars. This in turn underlined the importance of proceeding quickly with the development of an articulation retrofit for freight car trucks and/or with other changes in order to reduce the track damage being caused by these vehicles.
(CN Reports 147, 143, 150, 144).
- . Evaluation and testing of the Railway Engineering Associates articulated trucks established their capability for stable performance at high speeds under an empty car and to significantly reduce the mean lateral curving force for leading axles compared to a standard truck. To minimize the resources that would be required for the widespread utilization of such a truck, it was decided to attempt to apply the steering concept to conventional freight trucks, thus permitting the retention of standard side frames and bolsters and thereby retaining compatibility with existing truck components and maintenance support facilities. Through theoretical analysis and field testing of a carset of prototype trucks a satisfactory design was achieved for an articulation retrofit (designated DR-1, Steering Assembly)
- . Economic analyses made established that the large scale use of such retrofitted trucks would result in significant reduction in costs due to reductions in rail and wheel wear, fuel consumption and truck and vehicle component maintenance, and that such cost reductions would amply justify the initial capital and installation costs of the retrofit parts.
(CN Report 136 and 154).

Task 12 - Acquisition and evaluation of retrofitted self-steering trucks on a large scale in unit train service

Performing Organization - CN Rail Research

Transport Canada Contract No. - OSD79-00040

Synopsis of Task Activities

- . Following successful performance tests with the prototype carset of DR-1 steering trucks, ten additional carsets were acquired for testing in revenue service. The trucks were fitted by CN to 100-ton rotary dump gondolas. In addition, two cars equipped with conventional trucks were selected to act as a control population.

- . After one year of favourable operation, a further 100 carsets of DR-1 trucks were acquired to enlarge operating experience and fitted to 100-ton rotary dump gondolas. Of this group, 5 additional conventional cars and 5 DR-1 equipped cars were introduced into the wheel wear test populations, giving a total of 15 DR-1 cars and 7 conventional control cars. All these 22 test cars and the majority of the additional DR-1 cars were fitted with new CJ-36 Class C two-wear cast steel wheels with wide flange CN Heumann tread contour. This contour is one which achieves single point contact with new 132-lb. AREA rail section.
- . The majority of cars were operated between Luscar, Alberta and Vancouver, British Columbia on the CN South Line through the Rocky Mountains. This particular route was carrying 50 million gross tons per annum. Approximately 37% of the 680-mile one-way route is curved track. In that operation, the cars are turned for each round trip between the mine and ocean terminal.
- . Two mechanical problems with the trucks were identified through mechanical inspection fairly early in the retrofit program. The first of these was the rupture of the bolts securing the roller bearing adapters to the steering castings. Following testing of alternate bolt metallurgies, a lower tensile strength, more ductile material was selected. The improved bolts were retrofitted to the carsets already delivered and used in the manufacture of the remaining carsets.
- . The second problem related to the rubber bushing at the steering casting connection. An improved elastomeric bushing was developed by the manufacturer. The new type bushing were retrofitted to the carsets already delivered, and used in the manufacture of the remaining carsets.
- . Wheel wear measurements were taken on the test and control cars at intervals up to 250,000 miles, using the CN-developed precision wheel profilometer and computer software data analysis program. Five separate parameters were measured as follows:
 - Wheel flange cross-sectional area loss.
 - Wheel tread cross-sectional area loss.
 - Reduction in wheelset flange thickness.
 - Increase in wheelset flange height
 - Reduction in wheelset rim thickness due to wheel profiling operation.
 - (a) to original CN Heumann WF (wide flange) contour, or
 - (b) to AAR minimum requirements of NF (narrow flange) contour.
- . The incidence of wheelset removals from the entire fleet of DR-1 cars and the control cars was monitored.

- . Methodology was developed for measuring the reduction in curve resistance attributable to the DR-1 trucks in order to derive the corresponding reduction in fuel consumption. The method involved the use of dynamometer couplers between blocks of DR-1 and standard cars in a single train. High sensitivity semiconductor strain gauges and electronic equipment for this purpose were developed and tested and a dynamometer coupler calibrated. (The planned field measurements were not, however, carried out)

Reports and Published Papers

"Acquisition and Evaluation of Articulated Trucks on a Large Scale in Unit Train Service, Phase I" by R. P. Rennie, CN Rail Research, March 31, 1983.

CN Report No. - none assigned

TDC Report No. TP4232E

"Contribution of Self-Steering Trucks to Wheel Wear Reduction: CN Experience" by W. N. Caldwell. Proceedings of the International Conference on Contact Mechanics and Wheel/Rail Wear, Vancouver, B.C., July 6-9, 1982.

"The Development and Testing of a Steering Type Freight Car Truck for Heavy Service" by W. N. Caldwell, G. W. Cope and H. A. List. Proceedings of the Second International Heavy Haul Railway Conference, Colorado Springs, Colorado, Sept. 25 to Sept. 30, 1982.

"The Evaluation of Self-Steering Trucks in Revenue Service Operation; CN Experience" by R. W. Radford and W. N. Caldwell. Proceedings of the Conference on The Economics and Performance of Freight Car Trucks, Montreal, Canada, October 25 - 27, 1983.

Results/Findings

- . It was demonstrated that the DR-1 self steering trucks will perform satisfactorily in heavy haul unit train operations and that significant reductions in wheel/rail wear can be achieved through their use. In this evaluation, it was found that:

- Wheel flange cross-sectional area loss was reduced by a factor of 3 after 200,000 miles of service on the DR-1 equipped cars compared to the standard car trucks.
- Although comparative rail wear caused by the two types of cars was of course not possible, it was believed reasonable by the researchers to assume that rail gauge face wear in curved track was also reduced, on a per car basis by at least a factor of 3.
- There was no significant difference in measured wheel tread cross-sectional area loss between the DR-1 and the control

cars. It was concluded that this was because tread wear caused by tread braking predominates, and that any difference in tread wear due to the lower lateral creep of the DR-1 carset wheel relative to the standard carset wheels, was masked by the much greater tread wear due to braking which was common to both types of trucks. In the absence of data for reduction in loss of wheel tread cross-sectional area, no conclusion was possible as to reduction in rail head adhesive wear in curves.

- . An important result of the much reduced wheelset flange wear on the DR-1 cars is that it will lead to less rim metal loss in reprofiling a two-wear wheelset and will generally provide a full rim thickness of wearable metal with wide flange contour for the second wear cycle. This will significantly increase wheelset service mileage for two-wear wheels in their second service life. This benefit will also accrue to wheelsets removed from DR-1 equipped cars for non-wear condemning defects (shells, skid flats, built up tread, grooved tread, etc.) since less rim metal will be removed during reprofiling if less flange wear is present.

Task 13 - Investigate the steering characteristics and hunting stability of various "new generation" freight car trucks.

Performing Organization - Department of Research, Canadian Pacific Limited, with participation by personnel of the National Research Council Railway Laboratory.

TTD Contract Phase - II, IV, V

Synopsis of Task Activities

Phase II

- . A review was made of several mechanically steered and self-steering truck designs.
- . Preliminary planning for the comparative testing of various trucks was completed.
- . Field testing for a truck evaluation program was carried out on CP trackage near Calgary, Alberta. In this first phase of the program, five candidate trucks were selected for testing and comparison. These trucks included the Barber S-2 truck which was used as the reference truck, the Barber-Scheffel, DR-1 Radial, Devine-Scales Radial, Swing Motion, and the Ride Control. All the test trucks were equipped with CN 'A' profile wheelsets. In addition, the

Barber S-2 truck was tested with AAR profile wheels. Also an evaluation was made to assess the effect of C-PEP and Stucki Constant Contact Side Bearings on the performance of the Barber S-2 truck with "A" profile wheels.

Curving performance tests of the various trucks were carried out with loaded 100-ton coal cars on a 5 degree curve on the Laggan Subdivision (132 lb. 78 ft. staggered jointed rail). Lateral-vertical forces were measured by strain gauging the rail in five locations on the outer rail and one location on the inner rail. Two CN Research baseplates were used as support instrumentation to measure lateral-vertical forces at two locations on the outer rail of the curve. The angle-of-attack was measured at one location on the test curve using the CP-developed laser equipment developed by CP Research. Several test runs with various trucks were carried out at various speeds.

High speed stability tests of the various trucks were carried out with empty 100-ton bathtub coal cars on tangent track on the Brooks Subdivision on 115 lb. continuous welded rail. The cars were instrumented with accelerometers to establish speeds at which "hunting" commenced and were operated at various speeds.

Phase IV

- Field testing was carried out to evaluate the hunting and curving performance of the Railroad Dynamics Inc. (RDI) truck as compared with conventional Barber S-2 trucks. In addition, the effect of centre plate extension pads (C-PEP) on hunting and performance of the Barber S-2 truck was evaluated.

The field test work was carried out in the Calgary area and consisted of (a) high speed stability tests to determine the critical speed for the onset of hunting of the test trucks, and (b) curving performance tests to determine the lateral-vertical forces and the angle-of-attack of the wheelsets. The trucks were tested with new Heumann profile wheels and also with service-worn wheels which had accumulated approximately 94,000 miles in unit coal train service.

The high speed stability tests (maximum speed of 75 m.p.h.) were carried out with empty 100-ton bathtub coal cars on a two mile section of tangent track of the CP Brooks Subdivision with continuous welded rail. The leading axles of the two test trucks on each car were instrumented with accelerometers mounted on modified bearing end caps to record lateral acceleration.

The curving performance tests were carried out with loaded 100-ton bathtub coal cars on a 5 degree curve on the CP Laggan Subdivision. Lateral and vertical forces were measured on the high and low rail at one location in the test curve. The angle-of-attack instrumentation was located in the same place as that where the lateral and vertical forces were measured.

Phase V

- Field testing was carried out to investigate the curving and hunting performance of Elasto-Cushioned trucks. Four 100-ton bathtub cars were utilized, equipped with Barber S-2 heavy duty trucks and new experimental "A" profile wheels.

For the curving tests the cars were fully loaded. One of the cars was unmodified, one was equipped with C-PEP, one with rubber shear pads (Elastomeric LC-Pad manufactured by Lord Kinematics) inserted at the pedestal roof bearing adapter interface and one with both C-PEP and LC pads. The curving tests were carried out on a 5 degree curve with 132 lb. 78 ft. staggered jointed rail on the CP Laggan Subdivision. Prior to the tests, the 5 degree curve was instrumented to measure lateral and vertical forces at both rails as well as angle-of-attack. Data were collected for operation at various speeds under two conditions, the first utilizing LC-Pads of 21,000 lb/in shear stiffness and the second with pads of 15,000 lb/in shear stiffness.

For the hunting tests, the cars were empty and three of them were modified with LC-Pads and C-PEP as for the curving tests. The four cars were instrumented with accelerometers and video cameras were mounted on the cars equipped with the LC-pads. The tests were carried out on a two-mile tangent of the CP Brooks Subdivision laid with 115 lb. CWR. Runs were made at various speeds,

- The theoretical curving performances of four different freight car trucks under heavy axle loading conditions were compared using a non-linear steady-state curving model. The four trucks were the Barber S-2, Barber-Sheffel, DR-1 and a theoretical rigid frame truck. For the latter, an interaxle shear stiffness comparable to the BS-2 truck was assumed. Computer results were obtained under both relatively new and worn wheel/rail conditions.

Reports

"Comparative Performance of Type II Trucks", by H. Ghonem and R. Gonsalves, Department of Research, Canadian Pacific Limited, November, 1978.

CP Report No. - S576-81

TDC Report No. - TP2372

This report is also included as pages 184-308 of the Canadian Pacific final report on Phase II, "Track/Train Dynamics Volume I, 1978", TDC Report No. TP4576E (no CP number).

"Railroad Dynamics Incorporated (RDI) Truck Evaluation Test", by R. Gonsalves, W. Pak and G. Izbinsky, Department of Research, Canadian Pacific Limited, March 1981.

CP Report No. - S670-81

TDC Report No. - TP2970

This report is also included as pages 1-68 of the Canadian Pacific final report on Phase IV, "Track/Train Dynamics Volume 2, 1981, "TDC Report No. TP3120 (no CP number).

"Elasto-Cushion Truck Performance Study", by R. Gonsalves, W. Pak and G. Izbinsky, Department of Research, Canadian Pacific Limited, October 1982.

CP Report No. - S714-82

TDC Report No. - TP3283E

This report is also included as pages 1-23 of the Canadian Pacific final report on Phase V, "Track/Train Dynamics Volume 3, 1982", TDC Report No. TP4183E (no CP number).

"Theoretical Curving Performance of Four Freight Car Trucks", by W. Pak and G. Rosval, Department of Research, Canadian Pacific Limited, December 1981.

CP Report No. - S712-82

TDC Report No. - TP3449

This report is also included as pages 24-51 of the Canadian Pacific final report on Phase V, "Track/Train Dynamics Volume 3, 1982, TDC Report No. TP4183E (no CP number).

Results/Findings

A great deal of information was derived regarding the curving and tracking performance of "new generation" truck designs. It was demonstrated that although a number of these improve both curving and tracking performance, others achieve improvement in only one area, and hence only partially meet the performance objectives desired by many railway operators.

Task 14 - Obtain quantitative data on the performance of conventional and radial freight car trucks, particularly with respect to wheel wear.

Performing Organization - Department of Research, Canadian Pacific Limited.

Transport Canada Contract No. - OSD81 - 00074

Synopsis of Task Activities

- Five carsets of Barber-Scheffel trucks were assembled and installed on five 100-ton CP Rail bathtub coal cars in Calgary. Another three similar cars were equipped with conventional Barber S2-C trucks for baseline comparison. All eight cars were equipped with CP standard Heumann profile wheels. Initial wheel measurements were made using a wheel profilometer.

- . All eight cars were placed in unit coal train revenue service in January, 1982 between Fording (loading point) and Roberts Bank, B.C. (unloading point). Route distance is approximately 700 miles (1120 km) of which approximately 40% is curved. The cars were turned every 6 months (approximately 60,000 miles/96,000 km).
- . Five carsets of DR-2 trucks (a conventional 3-piece truck retrofitted with over-the-bolster steering arms) were installed on five additional similar CP Rail bathtub coal cars at Hamilton, Ont.. Initial wheel measurements were made. The cars were placed in unit coal train revenue service in June 1982 in the same consist as the other five test cars and three control cars.
- . Field inspection of trucks were carried out and wheel measurements were made at Revelstoke, B.C. at approximately 70,000 miles and approximately 130,000 miles. Four wheel wear parameters were monitored through the use of a wheel profilometer and a calibrated AAR finger gauge to make the wheel measurements. The four parameters were:
 - Reduction in wheel flange cross-sectional area
 - Reduction in wheel tread cross-sectional area
 - Reduction in wheel flange thickness
 - Reduction in wheel flange height

The wheel profilometer used was that developed by the Department of Research, Canadian Pacific (see task "Design and develop a wheel profilometer").

Note: After approximately 130,000 miles of revenue service operation, the DR-2 truck test was discontinued due to problems experienced with the steering arm interconnecting links on those trucks.

Reports

"Radial Axle Truck Tests", V. Khatchadourian, Department of Research, Canadian Pacific Limited, December 1983.
 CP Report No. - (not assigned at time of writing)
 TDC Report No. - TP5271E

Results/Findings

- . The average wheel flange wear for both types of radial trucks after approximately 130,000 miles of revenue service operation, obtained from finger gauge measurements, was found to be approximately 25 percent of that for the Barber SC-2 trucks control cars, and the tread wear approximately 78 percent.
- . From wheel profiles collected utilizing the wheel profilometer it was found that:

- the flange cross sectional area loss on the wheels of the Barber-Scheffel and the DR-2 trucks was approximately 22 percent of that on the wheels of the control cars.
- the tread cross sectional area loss on the wheels of the Barber-Scheffel trucks was found to be approximately 65 percent of that on the wheels of the control cars. On the wheels of the DR-2 trucks, the loss was slightly higher than that on the Barber-Scheffel trucks up to about 90,000 miles and slightly lower at higher mileages.

Task 15 - Establish the capability of a Canadian-developed steady-state mathematical freight car truck curving model (1) to predict freight car truck curving performance(2).

Performing Organization - DSL Dynamic Sciences Limited (DSL) with input from Wyle Laboratories of Colorado Springs.

Transport Canada Contract No. - OSD80 - 00093

Synopsis of Task Activities

- . The curving model was made operational.
- . Extensive model runs were made, utilizing seven different freight car truck designs and various operational parameters (i.e. degree of curve, superelevation, speed, loaded/empty). Operation of the following truck designs were simulated:

Type I

- (1) ACF Ride Control (100-ton)

Type II

- | | |
|---------------------|---------------------------|
| (2) Dresser DR-1 | (5) Maxiride 100 |
| (3) Barber-Scheffel | (6) National Swing Motion |
| (4) Devine-Scales | (7) ACF |

-
- (1) The model originated with CN Rail Research Centre but the rights to its use were purchased by DSL.
 - (2) Through comparison of outputs derived from exercise of the model with measured data obtained from an extensive test program performed by Wyle Laboratories of Colorado Springs, as part of Wyle's contract with the U.S. Federal Railway Administration on the Truck Truck Design Optimization Project (TDOP). The data were provided to Transport Canada (through DSL) under a U.S./Canada Joint Research Project.

- . Comparison was made between theoretical and measured performance data provided by Wyle Laboratories.

Reports

"Curving Performance Analysis of Freight Car Trucks" by R. Young and P. P. Marcotte, DSL Dynamic Sciences, September 1981.
TDC Report No. - TP3211E

Results/Findings

The work demonstrated that:

- The model can predict trends in the steady-state curving behaviour of rail vehicles, and can provide explanations for these trends. In particular, the model confirmed the test results which showed that steering trucks produce lower lateral forces as compared to non-steering trucks.
- The model can be used to study various configurations of railway trucks under a wide range of operating conditions such as track curvature, superelevation, and vehicle speed.
- The model can complement experimental testing of rail vehicles. Firstly, it can predict results which are either difficult or impractical to measure experimentally; for example: angles-of-attack and flange forces. Secondly, it can be used to determine performance of vehicles for conditions which have not been tested. A specific example is the comparison of the Type I and Type II trucks. The experimental results for the two could not be compared because different wheel profiles were used in the tests. However, the comparison was made using the theoretical model.
- The model can demonstrate the effects of variations in parameter values on curving performance. This can be useful in the evaluation of new designs of rail vehicle trucks, or in modifications to existing designs.

Task 16 - Evaluate and compare, by computer analysis, the reduction in rail wear and other railway operating cost components expected to result from the use of improved freight car truck designs (Type II) in place of the conventional three-piece truck (Type I)

Performing Organization - Canadian Institute of Guided Ground Transport (CIGGT) with input from Wyle Laboratories of Colorado Springs (1).

Transport Canada Contract No. - OSD79 - 00102

Synopsis of Task Activities

- . Vehicle and track quality (U.S. lines) parameters and dynamic performance measurements necessary for running the wear portion of the CIGGT Road Maintenance Cost Model (RMCN) were obtained from Wyle Laboratories for the following truck designs:

Type II

- Barber-Scheffel
- Devine-Scales
- Dresser DR-1
- Maxiride
- National Swing Motion

Type I

- Barber S-2-C
- ASF Ride Control

- . Track quality parameters for Canadian lines were developed.
- . Refinements were made to the RMCN, the costing routine finalized and necessary modifications incorporated into the computer program.
- . Data re acquisition costs, track maintenance costs (other than rail-wear), fuel consumption pertaining to the various trucks were obtained from Wyle Laboratories.

(1) The data provided by Wyle Laboratories was developed through an extensive test program carried out by Wyle Laboratories under contract with the U. S. Federal Railway Administration on the Truck Design Optimization Project (TDOP) and was provided to Transport Canada (through CIGGT) under a U. S./Canada Joint Research Project.

- . RCMC computer runs were made for various track qualities, curvature, speed and other conditions for the various trucks.
- . The economic analysis was completed.

Reports

"Rail Wear Economic Analysis for Type II Trucks", by E. R. McIlveen et al., Canadian Institute of Guided Ground Transport, August 1982.
CIGGT Report No. - 82-3 TDC Report No. - TP3863E

Results/Findings

- . It was found that:
 - performance and expected cost savings varied widely among the trucks and according to the various physical circumstances (curvature, tonnage, etc.). There were no clearly dominant trends.
 - the Type II trucks provide an economic advantage over standard trucks in only certain circumstances, and before a decision concerning the use of Type II trucks is made, a detailed analysis must be performed, taking into consideration the conditions under which the trucks are to operate.

Task 17 - Design and develop a wheel profilometer

Performing Organization - Department of Research, Canadian Pacific Limited.

TTD Contract Phase - V

Synopsis of Task Activities

- . The "floating" concept for a profilometer system previously developed by the CP Department of Research (CP Report No. - S655-81, Concept of a Profilometer for Rail Wear Determination) was further refined, design of hardware for wheel measurement and of software completed, measuring heads manufactured and the complete system tested.

Reports

"A Wheel/Rail Profilometer System, Vol. I and II", by G. Izbinsky,

H. Shrekinger and H. Soares, Department of Research, Canadian Pacific Limited, February 1984.

CP Report No. - T-805-84

TDC Report No. - TP5229E

Results/Findings

A rail profilometer system was developed with an estimated accuracy of:

- tread wear - plus or minus .16 mm (98% probability)
- flange wear - plus or minus .198 mm (98% probability)
- tread area wear - less than 10 mm²
- flange area wear - less than 3 mm²

Task 18 - Conduct a study of crack initiation in 100-ton coal car truck bolsters.

Performing Organization - Department of Research, Canadian Pacific Limited, with participation by personnel of the Physical Metallurgy Research Laboratories at CANMET, the National Research Council Railway Laboratory and the Mechanical Engineering Laboratory of McGill University.

TTD Contract Phase - II

Synopsis of Task Activities

- . A preliminary literature review was carried out and initial laboratory testing commenced in association with the National Research Council Rail Laboratory, to obtain quantitative data on failures.
- . Following preliminary static testing, a dynamic field test was carried out on the CP Thompson Subdivision to determine stress levels on the truck bolster of a loaded 100-ton car.
- . The data from the field tests carried out on the Thompson Subdivision were analyzed. The analyses of the data enabled stress distributions to be obtained at the point on the bolster where cracks were appearing. A relationship between the depth of rail surface defects and stress levels in the bolster was then established using the rail surface defect data obtained from the CP Track Recorder Car. From these analyses, the fatigue life of a 100-ton car truck bolster was established.
- . Metallurgical examination of the snubber pockets of a randomly chosen

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"Study of Crack Initiation in 100-ton Coal Car Truck Bolsters", by H. Ghonem, Department of Research, Canadian Pacific Limited, March 1978.
CP Report No. - S561-78 TDC Report No. - TP1681

This report is also included as pages 1-63 of the Canadian Pacific final report on Phase II, "Track/Train Dynamics Volume 1, 1978".
TDC Report No. - TP4576E (no CP number).

Causes of crack initiation in the truck bolsters were identified and recommendations for preventative measures were developed.

4.3 Track

Task 19 - Design and construct a fixed track structures test facility.

Performing Organization - CN Rail Research

TTD Contract Phase - I and II

Synopsis of Task Activities

Phase I

- . The design and construction of a track structures test facility at the CN Technical Research Centre proceeded to the point where:
 - (i) All fixed ground-installed equipment was in place.
 - (ii) All mechanical and electrical equipment was on hand.
 - (iii) A preliminary test program had been prepared.

Phase II

- . The track structures test facility was completed.

Reports

No final report was prepared on this work. However, a photograph and brief description of the facility appears on page 1 of CN Report No. 131 "Track Structures Test Facility, Report No. 1, Displacement of Newly Constructed Concrete Tie Track Under Static Lateral Load (Zero Vertical Load)". Additional information on the facility is included on pages 2 and 3 of CN Report No. 135 (TP 1331) "Track Structures Test Facility, Report No. 3, Performance of Concrete Tie Track Structures Under Repeated Low Speed Heavy Rolling Load" and on pages 1 and 2 of CN Report No. 162 (TP 2650) "Track Structures Test Facility, Progress Report No. 4, Concrete Tie Center Bending Moments with Track Settlement and Frost Heave".

Results/Findings

The ability was acquired to conduct a variety of track structures tests, which could not be conducted on operated trackage.

research program and is described in the report "Static Track Gauge Widening Tests, October 1972, Lateral Strength of Track" by J. R. Lundgren, CN Rail Research, December 1972.
CN Report No. - 109 TDC Report No. - none assigned

Results/Findings

- . From analysis of the field test data and theoretical calculations it was found that:

- Field Test Results

Rail tipping on 100-lb. rail commenced at an L/V loading ratio of 0.68.

Wood crushing and/or spike bending commenced at an L/V loading ratio of approximately 1.44.

Lateral rail slippage on the single shoulder tie plate commenced at an L/V loading ratio of 0.38.

Tie plate lateral slippage on the wooden tie commenced at an L/V loading ratio of 0.04 - 0.3. This was not clearly defined because of some uncertainty in the frictional loss between wheel and greased rail during the static jacking tests.

It is impossible through static rail jacking tests to define the L/V loading ratio at which progressive gauge widening commences. It appears that accelerated damage begins at L/V ratios in the order of 1.0.

- Theoretical Analysis

Rail tip-up commences when the resultant of the lateral and vertical wheel load passes through the edge of the base of the rail.

New Rail	132-lb.	L/V = 0.632
	115-lb.	= 0.620
	100-lb.	= 0.687
	85-lb.	= 0.727

Worn rail will tip more readily than new rail.

Worn Rail	132-lb.	L/V = 0.593
	115-lb.	= 0.588
	100-lb.	= 0.662
	85-lb.	= 0.711

The coefficient of friction between steel tie plate and wooden tie is of great significance in the transmission of lateral load to the tie plate fasteners.

For similar L/V loading ratios, 100-ton cars transmit greater lateral loads into the ties than do 70-ton cars.

- With the "rigid" conventional cut spike rail fastening system, the lateral and torsional stiffness of the rail cannot be effectively utilized in the distribution of lateral loading without the occurrence of damaging deformation in the rail fastener system at the point of load application.

Task 21 - Develop a simpler technique for measuring track modulus.

Performing Organization - CN Rail Research

TTD Contract Phase - V, VII, and VIII

Synopsis of Task Activities

Phase V

- . Modulus measurements were taken with rod and precise level (conventional method) on the Test Track at the Research Centre. Displacement transducers were located along the track to measure vertical rail deflections under slowly moving vehicles.
- . Measured data were analyzed to obtain correlation of the two measurement techniques.

Phase VII

- . Studies were made of the various parameters which effect the measurement of track modulus and of methods of measuring track modulus from wayside and from a moving vehicle.

Phase VIII

- . Studies were made of the effect of track geometry (particularly surface roughness), on the various instrument configurations envisaged for measuring modulus from a moving vehicle.

Reports

"Track Structures Test Facility, Progress Report No. 5, The Measurement

of Track Modulus", by A. Charenko and J. F. Scott, CN Rail Research, January 1982.

CN Report No. - 165

TDC Report No. - TP3586

Results/Findings

. On the basis of many track deflection measurements taken on both concrete and wood tie track, under both frozen and unfrozen conditions, six different methods of determining track modulus were evaluated. It was concluded that:

- The most convenient method of determining track modulus from wayside is through the measurement of absolute single point rail deflections directly under the wheels of a heavily loaded vehicle. These deflections should then be fed into the beam on elastic foundation theory and a modulus value calculated.
- The above method should replace the traditionally accepted but tedious method of measuring rail static deflection waveforms under light and heavy vehicles.
- No matter which methods are used to determine track moduli, the scatter in data will be considerable. We should forget about searching for accuracies of $\pm 5\%$ or $\pm 10\%$ and be willing to accept anything within the range of $\pm 40\%$. It should be sufficient to categorize roadbed quality into a limited number of ranges (three to six).
- Resolution on measurement of rail deflection should be in the order of $\pm .001$ in. Lack of accuracy in measurement should be eliminated as one of the variables contributing to scatter in computed moduli values.
- A light vehicle by itself is useless for the measurement of track modulus. Moduli should be measured only under heavy vehicles representative of the traffic on the territory in question.
- The beam on elastic foundation theory provides an acceptable means of computing track moduli from measured rail deflections.
- Roadbed quality can be categorized in terms of vertical rail deflections. The beam on elastic foundation theory may be utilized to convert deflections to track moduli.

. It was also concluded that the only practicable means of gathering the necessary large volume of deflection data required to be of any real value to the railway track engineer is to take the measurements from a moving vehicle, and that the development of this concept should proceed.

Task 22 - Investigate the phenomenon of rail corrugations.

Performing Organization - Department of Research, Canadian Pacific Limited with participation by the National Research Council of Canada.

TTD Contract Phase - I and II

Synopsis of Task Activities

Phase I

- . Two programs of field observations and measurements of long wavelength rail corrugations were conducted at several corrugation-affected sites on the CP Rail Shuswap and Mountain Subdivisions near Revelstoke, B.C., during the periods December 4-6 1973 and April 30 - May 2, 1974, respectively. During these periods, discussions were held with the track maintenance personnel, measurements of corrugation profiles were made, rail lubricant distribution patterns observed, rail metal and lubricant samples collected, wheel conditions observed and information obtained on traffic distribution, rail-grinding procedures and other relevant parameters.
- . Rail metal samples were sectioned, polished, etched and photographed to facilitate examination of the grain structure using a scanning electron microscope.
- . Chemical analyses were made of grease samples collected to identify impurities.
- . Theoretical studies were conducted of wheel/rail contact stresses, and of wear and fatigue mechanisms including the influence of rail metallurgy and lubrication on these.

Phase II

- . Meetings were convened with NRC and others to discuss and formulate a program for photographing and instrumenting a wheelset to measure curving performance and determine whether there might exist any correlation with corrugation formation.
- . A mission for the high speed filming of wheel/rail interaction and measurements of dynamic behaviour of a wheelset in a moving train was conducted over corrugated and non-corrugated track on the CP Rail Thompson Subdivision during the week of May 17, 1976. Two 100-ton cars were instrumented (one loaded and one light) employing accelerometers and force gauges. The loaded car was equipped with new cast

steel wheels. Wheels on the light car were worn wrought steel. One of the purposes of the mission was to investigate the validity, or otherwise, of the theory that a "stick slip" mechanism of wheel/rail interaction occurs during curve negotiation and results in the formation of rail corrugation. The second purpose was to obtain information on the dynamic forces occurring.

- . The high speed films were viewed and a detailed analysis made of some 1500 frames of the portions of the film taken while operating over severely and mildly corrugated rail sections. Each frame was examined for evidence of lateral cyclic wheel oscillations. The low rail/wheel flange clearance on each frame was established with an accuracy of plus or minus 1 mm. (plus or minus .04").
- . Field trials were carried out in collaboration with the National Research Council to attempt to determine whether there might exist any inter-relationship between wheelset behaviour and corrugation formation. The tests were conducted on a loaded 100-ton coal car on the Thompson Subdivision between Kamloops and North Bend on October 20th, 1974. Instrumentation consisted of vertical, lateral and longitudinal accelerometers mounted on the axle bearing caps at both ends of an axle on one truck of the coal car. This test was similar to the test carried out previously except that the wheelsets used in this test were severely worn as compared to the new and moderately worn wheelsets used in the previous test. The test results were analyzed by personnel of the National Research Council in Ottawa.

Reports

"Track/Train Dynamics Report #4, Rail Corrugations" by J. Kalousek, Department of Research, Canadian Pacific Limited, February 1975.
CP Report No. - S488-75 TDC Report No. - none assigned.

This report is also included as Section E of the Canadian Pacific final report on Phase - I - "Track Train Dynamics Phase I", March 1975 (not numbered).

"High Speed Filming of Wheel/Rail Interaction" by the J. Kalousek, National Research Council of Canada, Division of Mechanical Engineering, Vancouver, B.C., and R. Gonsalves, Department of Research, Canadian Pacific Limited, March 1978.
CP Report No. - S557 - 78 TDC Report No. - TP1474.

"Dynamic Measurements of a Heavy Car Wheelset Over Rails Subject to Corrugation" by F. B. Blader, Railway Laboratory, National Research Council of Canada.
TDC Report No. - TP1394.

Results/Findings

- . The mechanics of the formation of long wavelength rail corrugations was identified.

- . Factors which would likely reduce or eliminate the formation of rail corrugations were identified.
(CP Report No. - S488-75)
- . The high speed film revealed no lateral cyclic oscillations in the wheel/rail interface. Thus there was no indication of the occurrence of the "stick slip" phenomenon and it was concluded that this is due to the presence of a large amount of grease (in boundary lubrication terms) on the rails from flange lubricators.
- . Variations in the low rail/wheel flange clearances were attributed in part to dynamic gauge widening.
(CP Report No. - S5557-18).
- . The dynamic measurements provided useful information on frequency and vertical acceleration of loaded and unloaded cars operating on corrugated and non-corrugated rail.
(TDC Report No. - TP1394).

Task 23 - Investigate the nature and magnitude of rail wear under heavy traffic conditions.

Performing Organization - Department of Research, Canadian Pacific Limited, with participation by personnel of:

- the Engineering and Metallurgy Departments of McGill University.
- the Department of Energy, Mines and Resources, Ottawa.
- Cominco Ltd.

TTD Contract Phase - II

Synopsis of Task Activities

- . Track wear was studied theoretically with emphasis concentrated on wear on the high rail in curves, and including an appraisal of a design concept for a Wheel Rail Interaction Simulator proposed by the R & D Division of the Ontario M.O.T.
- . A study in the area of wheel/rail lubrication was carried out by a graduate engineering student at McGill University (see task "Development of a new rail curve grease to reduce wear").
- . A visit was made to the CP Transcona Welding Plant to collect samples of welded rail and examine the state-of-the-art for field welding of rail.
- . The mechanical properties and weldability of the six basic rail

steels produced in North America were reviewed.

- . Macro-etched cross samples of the various rails were prepared and a Vickers hardness survey taken.
- . Samples were taken from the heads of various rails, prepared for micro-examination and the macro-structure of the rails examined.
- . A statistical sample of rail head profiles was collected from a section of curved track west of Calgary to provide data on wear and plastic deformation.
- . Scanning Electron Microscope examinations were made of samples of in-track rail and debris obtained from the field.
- . A proposal for the mechanical properties of future rails was developed.
- . The heat-treating vs alloying methods for achieving improved physical properties were reviewed and considered and, as well, heat-treating plus alloying.

Reports and Published Papers

"Track/Train Dynamics Report #6, Rail Metallurgy", by J. Kalousek, Department of Research, Canadian Pacific Limited, and G. Beynon, Cominco Ltd., July 1975.

CP Report No. - S497-75

TDC Report No. - none assigned.

This report is also included as pages 64-109 of the Canadian Pacific final report on Phase II, "Track/Train Dynamics Volume I, 1978", TDC Report No. - TP4576E (no CP number).

"Rail Wear Under Heavy Traffic Conditions" by J. Kalousek and A. E. Bethune, Department of Research, Canadian Pacific Limited. A paper presented at the Symposium on Steel, Stainless Steel and Related Alloys, sponsored by ASTM Committee A1, Denver, Colo., Nov. 1976 and included in ASTM Special Technical Publication STP644.

Results/Findings

An excellent insight was acquired into the properties of the various rails produced commercially in North America, and recommendations developed for the properties of improved rail and how best to achieve these.

Subsequent Work

Soon after completion of this work, the principal researcher, Dr. J.

Kalousek, resigned from Canadian Pacific to take an appointment at the Western Laboratory of the National Research Council (NRC) in Vancouver where he continued his rail research with support from both the Transportation Development Centre and Canadian Pacific. In late 1981 a joint NRC/University of Rhode Island research program commenced, aimed at developing a wear and fatigue model for railway rail, with support from the Transportation Development Centre and the Association of American Railroads. The first report on that program is entitled "Establishment of Quantitative Wear and Fatigue Model for Railway Rail, 1981/82 Progress Report" by J. Kalousek and H. Ghonem, April 1983. (NRC report No. - LTR-WE-38, TDC Report No. - TP4347E). That report consists of five papers on the subject of rail wear, as follows:

"Observations of Rail Wear on Heavy Haul Railway Lines", by H. Ghonem, J. Kalousek, D. H. Stone, D. Dibble, Proceedings of the International Symposium on Contact Mechanics and Wear of Rail/Wheel Systems, University of Waterloo - Solid Mechanics Division, 1983.

"Aspects of Plastic Deformation and Fatigue Damage in Pearlitic Rail Steels", by H. Ghonem, J. Kalousek, D. H. Stone, E. E. Laufer; Proceedings of the Second International Heavy Haul Conference, ASME 82 - HH - 31.

"Lubrication: Its Various Types and Effects on Rail/Wheel Forces and Wear", by J. Kalousek; Proceedings of the Rail and Wheel Lubrication Symposium, Railway Systems and Management Association, 1982.

"Lateral Creepage and its Effect on Wear in Rail Wheel Interface", by J. Kalousek, G. Rosval, H. Ghonem; Proceedings of the International Symposium on Contact Mechanics and Wear of Rail/Wheel Systems, University of Waterloo - Solid Mechanics Division, 1983.

"On the Fracture and Wear Characteristics of Chromium - Molybdenum Bainitic Steels", by H. Ghonem, J. Kalousek, D. H. Stone; Proceedings of the International Conference on Recent Developments in Specialty Steels and Hard Materials, Pretoria, 1982.

Task 24 - Study the wear and fatigue characteristics of rail steel.

Performing Organization - Department of Research, Canadian Pacific Limited with participation by the AAR Technical Laboratory in Chicago, the McGill Micromechanics Laboratory, the NRCC Western Laboratory in Vancouver and the EM and R Physical Laboratory in Ottawa.

TTD Contract Phase - III and IV

Synopsis of Task Activities

Phase III

- . Studies were undertaken with the object of developing a mathematical rail failure model to predict safe inspection intervals and optimum rail replacement cycles, through prediction of wear process and fatigue crack initiations and growth in rails subjected to high in-track axle loads.
- . An analytical model was developed for fatigue crack initiation and propagation in rail material.
- . Rail failure criteria were established.

Phase IV

- . A computer model was developed to calculate the sub-surface stresses for the case of non-hertzian contact between wheel and rail.
- . Numerous analyses and tests of several different rail type samples were carried out at various participating laboratories to obtain data relevant to wear and fatigue characteristics, failure mode and expected behaviour in track.
- . A simplified theory concerning the formulation of an analytical model to describe the total wear on both high and low rails as a function of the angle-of-attack was developed. A theoretical rail life curve for different degrees of track curvature, derived by using the analytical model, was found to compare favourably with similar curves obtained from in-service field measurements of wear on rails of various metallurgies on several different railroads.

Reports and Published Papers

"Study of Fatigue Characteristics of Rail Steel", by H. Ghonem and W. Pak, Department of Research, Canadian Pacific Limited.

This report was not published separately but is included as pages 1-11 of the Canadian Pacific final report on Phase III, "Final Report, Track/Train Dynamics Program, Phase III, 1st October 1978 - 15th May, 1979".

CP Report No. - S601-79.

TDC Report No. TP2437.

"Manual for Three-Dimensional Sub-Surface Contact Stress Analysis Program for Wheel/Rail Interaction", by W. Pak, Department of Research, Canadian Pacific Limited, October 1980.

CP Report No. - S659-80

TDC Report No. - TP2792

This report is also included as pages 115-168 of the Canadian Pacific final report on Phase IV, "Track/Train Dynamics Volume 2, 1981", TDC Report No. - TP3120 (no CP number).

"The use of Angle-of-Attack Measurements to Estimate Rail Wear under Steady State Rolling Conditions" by H. Ghonem, Department of Research, Canadian Pacific Limited, and J. Kalousek, National Research Council. Proceedings of International Conference on Wheel/Rail Load and Displacement Measurement Techniques, Boston, Mass., Jan. 19-20, 1981, U. S. Department of Transportation Publication DOT-TSC-UMTA-82-3.

This paper is included as pages 240-272 of the Canadian Pacific Final Report on Phase IV "Track/Train Dynamics Volume 2, 1981".
TDC Report No. TP3120 (no CP number)

Results/Findings

- . Much information was gained concerning the wear and fatigue characteristics of rail steel.
- . A simplified analytical model to describe the total rail wear as a function of the angle-of-attack was developed.
- . Progress was made towards the development of a complete wear and fatigue model for railway rail.

Note: Further work on the development of a wear and fatigue model is currently in progress under a program at the NRC Western Laboratory in Vancouver and the University of Rhode Island. See notation "Subsequent Work" at conclusion of the task "Investigate the nature and magnitude of rail wear under heavy traffic conditions."

Task 25 - Develop a new rail curve grease to reduce wear

Performing Organization - Department of Research in co-operation with the Research Department of Imperial Oil Limited at Sarnia, Ontario, and the participation of personnel of the Department of Mechanical Engineering, McGill University.

TTD Contract Phase - III

Synopsis of Task Activities

- . A theoretical evaluation was made of the benefits of solid lubricants in reducing wheel wear.
- . An agreement was reached with Imperial Oil Enterprises Ltd. to undertake a joint research program to produce an experimental rail curve grease specifically formulated to inhibit crack nucleations and

resultant fatigue cracking.

- . A rolling ball fatigue tester was set up in the Imperial Oil Research Laboratory to enable evaluating the relative fatigue performance of two different rail metallurgies (standard carbon and Cro-Mo) and the benefit of various lubricants to extend the fatigue life.
- . Tests were conducted on specimens of both rail metallurgies, using four grease compositions, viz:
 - the current product being used by CP Rail
 - the current product plus water
 - the current product plus a fatigue inhibitor
 - the current product plus water plus a fatigue inhibitor

Reports

"Development of a New Rail Curve Grease" by C. Smith, Imperial Oil.

This report was not published separately but is included as pages 18 - 28 of the Canadian Pacific final report on Phase III, "Final Report, Track/Train Dynamics Program, Phase III, 1st October 1978 - 15th May 1979".

CP Report No. S601-79

TDC Report No. TP2437.

"A Novel Approach to Rail Lubrication" by R. G. Nkana, Department of Mechanical Engineering, McGill University, August 1976.

Results/Findings

- . The approach, used in the rolling ball tests, of combining current fatigue inhibiting technology with the current railcurve grease was unsuccessful in that the fatigue life of the grease was not extended. This was not consistent with previous experiences with that additive which consistently gave superior fatigue properties relative to base case formulations. The fatigue additive appeared to interfere with the additive package of the railcurve product to produce an antagonistic mixture. Also, water did not behave as expected.

It was concluded that a more fundamental approach to handle the problem of modifying the fatigue properties of the additive package being used in the railcurve product is needed, but no further work was carried out (Report by C. Smith).

- . An initial exploration of the concept of rail lubrication from the point of view of solid lubrication was carried out (report by R. Nkana).

Task 26 - Monitor, in the field, rates of wear on curves with premium rail steels and rail lubrication.

Performing Organization - CN Rail Research

TTD Contract Phase - IV

Synopsis of Task Activities

- . The objective of this task was to evaluate the wear rates of regular and premium rail steels, under heavy unit train traffic and various degrees of curvature with and without rail lubrication and to determine the performance and economics of these steels. The new rail profilometer was to be used in the work.
- . Due to severe weather conditions and other circumstances the work as planned was not carried out.
- . Considerable information on this subject of wear on premium rails under heavy traffic was, however, generated by CN Rail Research through detailed wear measurements taken over a four-year period on bolted premium (alloyed) rails in twelve 8° curves on their Yale and Clearwater subdivisions in British Columbia, which at that time were carrying roughly 30 million gross tons of traffic (MGT) annually.
- . The four types of premium rails were:
 - Chrome Columbian
 - Chrome
 - Manganese Vanadium
 - High Siliconand were laid on wood ties during the 1974 and 1975 work seasons.
- . Wear measurements were taken in June of each year for the years 1975 - 1978 inclusive, using the CN standard rail gauge.
- . Over the four-year test period rail lubrication conditions varied (at times non-existent on some curves), thereby providing the opportunity to evaluate the influence of lubrication on wear and estimated rail life.
- . Based on the rail wear measurements and the accumulated tonnage on each test installation at the time of annual measurement, the total rail life (including transposition) was estimated in MGT for each rail type.

Reports

"Evaluation of Premium Rail on 8 degree Curves on the B. C. South Line" by P. M. Gardiner, R. G. Butler, C. J. Dalton and J. F. Scott, CN Rail Research, January 1979.

CN Report No. - 152

TDC Report No. - TP2567.

Results/Findings

- . Rail life estimates showed that the Manganese Vanadium rail will survive roughly twice as long as the High Silicon rail and that the two types of Chrome rail will survive between three and three-and-one-half times as long as the High Silicon rail.
- . Where rail lubrication was non-existent or variable over the four-year test period, estimated life for premium Chrome rail was reduced by roughly 60% for the high rail.

Task 27 - The production of experimental heats of Chromium - Molybdenum alloy rail steel, and the rolling and testing of rail from these heats.

Performing Organization - Department of Research, Canadian Pacific Limited, with participation by personnel of:

- Algoma Steel Corp. Ltd.
- Sydney Steel Corp.
- Climax Molybdenum Co.
- Metallurgy Section of CANMET
- National Research Council of Canada
- Facility for Accelerated Service Testing (FAST), Pueblo, Colo.

TTD Contract Phase - II

Synopsis of Task Activities

- . An experimental heat (heat #C-5599 - Ingot cast) of Chromium - Molybdenum (Cro-Mo) alloy rail yielding approximately 85 tons of 132 lb. RE rail was produced by Algoma Steel. Problems were encountered in straightening the rails to meet railway specifications. Samples of the rails were sent to various laboratories for analysis and testing. Streaks of an acicular (martensitic) type of microstructure were found in the web of the rails during these analyses.
- . Representatives of the Algoma and Sydney Steel Corporations visited leading European steel mills in February, 1976, to gain a better understanding of European practices in the production of Cro-Mo and other types of alloyed rail and to review with those producers the results of the Canadian heat No. C5599.
- . Planning was completed for production of a second heat of Cro-Mo rail to the same chemistry as the initial heat, but to be produced with the continuous casting process. Production delays were encountered due to closure of the Algoma continuous casting facility

because of depressed market conditions, but a 100-ton heat was subsequently produced (heat No. 9273B) and rolled into 132 lb., 39 ft. rail length (71 lengths).

- . Experimental welding of the chrome molybdenum alloy rail was performed at the Canadian Pacific Transcona Rail Welding Plant to assess the effect of various pre-heat and post-heat cycles on microstructure. Weld specimens from the 13 sample welds produced were distributed to various co-operating agencies for metallographical examination and analysis.
- . Reports on metallurgical examinations of the Cro-Mo rail samples from heat 9273B made by the Dept. of Energy Mines and Resources, Climax Molybdenum Corp. and others were received and reviewed.
- . Fifty-five of the 39 foot experimental Cro-Mo alloy rails from heat 9273B were forwarded to the F.A.S.T facility in Pueblo, Colo., for installation and testing. Two rail lengths were installed in section 11 of the F.A.S.T. track to obtain data on the fatigue and wear characteristics. The remaining 53 rails were tested for uniformity of hardness. Average hardness was found to be 376 BHN with a minimum of 344 BHN and a maximum of 388 BHN.
- . Based on the earlier experimental welding, a welding procedure for the Cro-Mo rail was developed. Using this procedure, sixteen of the 39 ft. rails from heat 9273B were welded into 78 ft. lengths. Three samples were distributed to different organizations for metallurgical analysis of the weld zone.
- . Inspection of the two rails placed in section II of the F.A.S.T. loop, after 110 million gross tons (MGT) of traffic revealed no evidence of surface fatigue cracks nor any measurable level of head wear.
- . Twelve of the heat 9273B rails were welded at Pueblo and installed in Section 3 of the F.A.S.T. loop. Because of hardness values of up to 430 BHN at the head and base at the welds, the rails were removed from track and heat treated at the weld zone locations to reduce the hardness. The remaining rails were also welded, weld joints tempered, and 20 welded lengths placed in two 5 degree curves in Section 3 to enable comparison with Cro-Mo rails produced by CF & I and installed in the same curves. The two single rail lengths in section 11 were removed from track after 140 MGT because of bolt hole cracks in both and the occurrence of a transverse defect over one bolt hole on one of the rails.
- . The 20 welded lengths in section 3 were removed from track after an accumulation of 115 MGT consisting of programmed regimes of lubricated and dry rail conditions.

Reports and Published Papers

"Premium Rails: A Review of Options", by L. P. Trudeau, D.W.G. White

W. J. Craigen, Canada Centre for Mineral and Energy Technology (CANMET),
Report No. - MRP75-14 (ACT) (TR) (CF)

"Report on Development of High Strength Weldable Chromium-Molybdenum Rail", by H. Ghonem, Department of Research, Canadian Pacific Limited and J. Kalousek, Western Laboratory, Division of Mechanical Engineering, National Research Council, August 1978.
CP Report No. - S571-78 TDC Report No. - none assigned.

This report is also included as pages 110-156 of the Canadian Pacific final report on Phase II, "Track/Train Dynamics Volume I, 1978", TDC Report No. - TP4576E (no CP number).

"Effects of 'Streaks' on the Fracture Toughness of Chromium Molybdenum Rail Steel" by J. Kalousek, Western Laboratory, Division of Mechanical Engineering, National Research Council and D. E. Parsons and H. Ghonem, Department of Research, Canadian Pacific Limited, August 1980.
CP Report No. - S651-80 TDC Report No. - TP2726.

This report is also included as pages 196-212 of the Canadian Pacific final report on Phase IV, "Track/Train Dynamics Volume 2, 1981", TDC Report No. - TP3120 (no CP number).

"Evaluation of Algoma Cro-Mo Rail Steel for Canadian Pacific Railroad" by F. B. Fletcher, Climax Molybdenum Company, Jan. 23, 1976.
Report No. - J-4183. Copy held in TDC library.

"On the Performance of the Experimental Bainitic Chromium - Molybdenum Rail Steel, by H. Ghonem, Department of Research, Canadian Pacific Limited, April, 1982.
CP Report No. - S739-82 TDC Report No. - TP3726E

This report is also included as pages 124-153 of the Canadian Pacific final report on Phase V, "Track/Train Dynamics Volume 3, 1982", TDC Report No. - TP4183E (no CP number).

"A Perspectival Review of Rail Behaviour at the Facility for Accelerated Service Testing", by R. K. Steele, Transportation Test Centre, Pueblo, Colo., June 19, 1981.
Report No. FRA/TTC-81/07 (NTIS PB82 176470)

"On the Fracture and Wear Characteristics of Chromium - Molybdenum Bainitic Steels", by H. Ghonem, University of Rhode Island, J. Kalousek, National Research Council of Canada and D. H. Stone; Proceedings of the International Conference on Recent Developments in Specialty Steels and Hard Materials, Pretoria, 1982.

Note: A copy of this paper is included in the NRC report LTR-WE-38 "Establishment of Quantitative Wear and Fatigue Model for Railway Rail - 1981/82 Progress Report".
(TDC Report No. TP4347E)

"Alloy Rail Production - Visit to European Producers", by G. F. Morris and H. Jaeger, Algoma Steel Corporation and L. Trask, Sydney Steel

Corporation, March 16, 1976. This is an informal letter-type report. Copy held in TDC library.

Results/Findings

The understanding, by Canadian rail producers and users, of the problems inherent in the manufacture and welding of high strength alloy rail and of procedures necessary to circumvent these problems, was significantly enhanced.

Task 28 - Collect and compare data on wear of fully heat-treated Russian P-65 rail and Algoma 1% chromium rail.

Performing Organization - Department of Research, Canadian Pacific Limited, with participation by the Physical Metallurgy Research Laboratories, CANMET.

TTD Contract Phase - IV and V

Synopsis of Task Activities

- . 300 tons of fully heat-treated rail were obtained from the USSR as part of a Canada/USSR technical exchange program. This rail, referred to as P-65 rail, is 64.4 kg/m (129.8 lb./yd).
- . Spectrochemical analysis was carried out on samples of the P-65 rail and the findings compared with findings reported by the USSR and AREA and with findings from analyses of certain North American rail sections.
- . Hardness tests were carried out and the findings compared with those from tests of certain North American rail sections.
- . On the basis of the findings from the analyses and hardness tests it was concluded that the P-65 rail was suitable for installation in CP track for purposes of comparative wear testing with Algoma 1% Cr rail.
- . P-65 rail was installed in three test sites on the Pacific Region of CP Rail during 1981. The test sites included tangent track, spirals and curvature from 7.75 degrees to 9 degrees and were laid partially with 136 lb. (67.6 kg/m) Algoma 1% Cr rail. There were trackside rail lubricators in the vicinity of each test site. Annual traffic was approximately 50 million gross tons. Maximum axle load was approximately 32.5 tons and train speed 10 to 40 mph.
- . Periodic rail profile measurements and qualitative surface examinations were made during the period 1981-1983, and data recorded and analyzed.

Reports

"Analysis of P-65 Rail - Preliminary Report", by H. Ghonem, Department of Research, Canadian Pacific Limited, October 1979.
CP Report No. - S606-79 TDC Report No. - None assigned

This report is also included as pages 213-239 of the Canadian Pacific final report on Phase IV, "Track/Train Dynamics Volume 2, 1981, "TDC Report No. - TP3120 (no CP number).

"Field Evaluation of the Wear Performance of Russian P-65 Rail - Interim Report", by G. Rosval, Department of Research, Canadian Pacific Limited.
CP Report No. - S750-83 TDC Report No. - None assigned.

"Examination of Russian P-65, Oil Quenched, Tempered, Carbon-Steel 'Exchange' Rail", by D. E. Parsons et al., Physical Metallurgy Research Laboratories, CANMET, August 1980.
CANMET Report No. - MRP/PMRL 80-28(CF) TDC Report No. - None assigned.

"Field Evaluation of the Wear Performance of Russian P-65 Rail", by K. Griffin, Department of Research, Canadian Pacific Limited, December, 1983.
CP Report No. - S799-83 TDC Report No. - None assigned at time of writing of this Summary Report.

Results/Findings

From the analyses and field evaluations performed it was concluded that:

- On tangent track the Algoma 1% Cr rail generally exhibited 50% more vertical head wear and 30% more total head wear (area reduction) than the P-65 rail.
- On the high rail of fully developed curves, the Algoma 1% Cr rail typically exhibited up to 25% more total head wear than the P-65 rail. On the low rail of fully developed curves there was no consistently discernible difference in wear between the two rail types.
- The Algoma 1% Cr rail, being of larger cross sectional area than the P-65 rail, is able to sustain a greater amount of wear before reaching its condemning limit. When wear is expressed as a percentage of the condemning limit, the above mentioned conclusions become (1) on tangent track the Cr rail is inferior, (2) on the high rail both rail types are equivalent and (3) on the low rail the Cr rail is superior. These results are somewhat misleading, however, since the weight of the P-65 rail is more similar to that of 132 Lb. rail rather than the 136 lb. rail installed on the test sites.
- On the low rails of fully developed curves the P-65 is much more

susceptible to shell formation and the development of long-wavelength corrugations.

Task 29 - Develop a non-destructive method for determining the thermal stress in long welded rails (CWR) at any time during their life in track.

Performing Organization - CN Rail Research

TTD Contract Phase - V, VII, VIII and IX

Synopsis of Task Activities

Phase V

- . A literature survey was conducted to identify the existence of equipment and technical procedures to facilitate the measurement of thermal stresses in CWR. Eight different techniques were identified:
 - (1) British Rail's longitudinal rail force transducer.
 - (2) Ultrasonic method reported by FRA.
 - (3) Rail strain gauging.
 - (4) Mechanical extensometer method.
 - (5) Infrared distance measurement on long length (1000 ft.).
 - (6) Barkhausen electromagnetic methods.
 - (7) Residual stress relief methods (blind hole drilling).
 - (8) Miniaturized vibrating wire strain gauge.
- . It was decided to concentrate research effort on five of the techniques as follows:
 - (1) British Rail's longitudinal rail force transducer.
 - (2) Rail strain gauging.
 - (3) Mechanical extensometer method.
 - (4) Residual stress relief method (blind hole drilling).
 - (5) Miniaturized vibrating wire strain gauge.
- . The necessary materials were acquired and laboratory evaluation undertaken.

Phase VII

- . A series of miniaturized vibrating wire strain gauges were installed on a string of CWR near Brighton, Ont. on the CN Kingston Subdivision, prior to it being laid in track. Rail stress measurements were taken. The rail was laid and, subsequently, stress measurements were again taken on the instrumented string.

- . A computer program was prepared to manipulate the data, and data analysis was completed.
- . A survey of published literature on longitudinal rail stresses was undertaken.

Phase VIII

- . Theoretical studies were made of the effect of axial stresses on rail vibratory response.
- . Investigations were undertaken in an effort to determine how to proceed with setting up a laboratory test station for measurement of rail vibratory response under controlled and variable longitudinal rail force levels, and requirements for data acquisition and processing equipment.
- . Instrumentation for a new experiment to measure axial rail force at Garry, Ont. was designed and acquired.

Phase IX

- . Prior to laying, 4 strings of CWR at Garry, Ont. were instrumented to enable measuring of axial rail forces. A total of 74 extensometer measuring stations were set up at 50 and 100 ft. stations on the rails. The rails were installed in track and readings taken.
- . Work was progressed on development of a rail loading frame and instrumentation requirements for the laboratory investigation of relationships between transverse vibratory response and axial force in rail.
- . Theoretical work was carried out on the propagation of flexural waves in rail.
- . The quasi-static transverse compliance of the rail, while under the action of axial force, was investigated.

Note: Work on this task is being continued under Phase X of the TDC/CN Cooperative Railway Research Program, still in progress at the time of preparation of this progress report.

Reports

All reports on this work were incomplete at the time of preparation of this summary report. The following reports are planned (titles are tentative):

"Evaluation of Techniques for Monitoring Thermal Stresses in Long Welded Rail" (to cover work at Brighton, Ont.)

"Evaluation of Techniques for Monitoring Thermal Stresses in Long Welded Rail - Report No. 2" (to cover work at Garry, Ont.)

"Measurement of Absolute Longitudinal Rail Forces - Feasibility Study".

Results/Findings

Work incomplete.

Task 30 - Develop a satisfactory method for bringing strings of continuous welded rail (CWR) to the preferred laying temperature, by heating ahead of laying when using the Rail Change Out Machine (RCO).

Performing Organization - CN Rail Research

TTD Contract Phases - VII, VIII and IX

Synopsis of Task Activities

Note: With the introduction on CN of the practice of connecting together shop-welded quarter mile long strings of CWR by flash-butt welding ahead of the RCO (instead of by thermit welding after laying), two requirements became more urgent. These were:

- to lay the rail within the preferred laying temperature at all times in the rail-laying season.
- to have the capability to heat the rail (when necessary to do so to bring it to the preferred laying temperature) ahead of the RCO, rather than after laying.

Although rail heaters had been employed previously by CN when necessary to bring newly laid quarter mile strings to the desired temperature before spiking and anchoring, it was necessary to verify that satisfactory in-track temperatures would result if the rail was heated before passing through the RCO.

To verify this, tests were conducted during rail laying operations, using Electronic Distance Measuring (EMD) equipment to make accurate length measurements of the rail first in an unrestrained condition before heating and second after laying and fastening to the ties. These data, combined with rail temperature readings before laying, enabled quick and accurate calculation of the after-laying temperature of the rail.

Phases VII, VIII and IX

- . Tests were conducted during rail-laying operations at several different locations as follows:

- Redditt Sub. - M242.8
- Chatham Sub. - M75-81
M53-60
- Kingston Sub. - Port Hope, Ont.
Garry, Ont.

- . At each location, measurements of rail temperature and rail length were made (the length measurements made with EDM equipment):

- While the strings were laid out on rollers on the tie ends just ahead of the RCO machine. Rail assumed to be in a stress free condition.
- After new rail was laid and anchored in track following passage through rail heaters and the RCO machine.

Follow-up measurements with the EDM equipment were made at the Port Hope location some months later to ascertain if length changes had occurred over the winter.

- . The work demonstrated that for a rail-heating-ahead-of-the-RCO-operation to be successful, major modifications to the existing heaters would be required, and planning for the development of an improved rail heating system commenced.

Note: Work on this task is being continued under Phase X of the TDC/CN Cooperative Railway Research Program, still in progress at the time of preparation of this summary report.

Reports

"Determination of Stress-Free Temperatures and Force Levels in Continuous Welded Rail (CWR)" by J. F. Scott and C. J. Dalton, CN Rail Research, May 1982.
CN Report No. - 176

TDC Report No. - 3707E

Additional Reports Planned

"Use of Rail Heaters in Laying of Continuous Welded Rail".

Results/Findings

- . Significant improvement was achieved in the heating-ahead-of-the-RCO machine system, with consequent elimination of the need for use of a

rail destressing gang to follow the rail laying operation and resulting reduction in labour cost and in train delays.

Task 31 - Design and develop a rail profilometer.

Performing Organization - CN Rail Research

TTD Contract Phase - III and IV

Synopsis of Task Activities

Phase III

- . Various methods of precisely measuring rail wear were considered.
- . The method progressed was that already used for measuring wheel profiles; namely a series of x, y co-ordinate measurements of the rail cross section. This allowed the use of software for processing rail wear measurement data which had already been developing for processing wheel wear data.
- . A method of profilometer registration was selected, based on use of a standard rail splice bar grooved to provide an adequate reference point for wear measurements.
- . Drawings were prepared and a prototype constructed.

Phase IV

- . The accuracy and reliability of the prototype profilometer hardware and software was validated in the laboratory.
- . Rail wear measurement stations were established on 5 degree, 8 degree and 12 degree standard carbon rail curves in Montreal Yard and wear measurements taken at regular intervals.

Reports

"Rail Wear Measurement - Precision Rail Profilometer", by K.J.R. Mathewson, CN Rail Research, July 28, 1977.
CN Report No. - M134 TDC Report No. - TP1223

Results/Findings

- . An improved ability for obtaining rail wear data was achieved, relative to conventional methods. Furthermore, the supporting software

package enables the rapid and accurate calculation and comparison of rail wear criteria (e.g. gauge face wear and head wear) and facilitates the monitoring of rail head profiles over a long period of time in order to establish patterns of wear.

Task 32 - Design and develop a rail profilometer.

Performing Organization - Department of Research, Canadian Pacific Limited.

TTD Contract Phase - V

Synopsis of Task Activities

- . Existing methods employed to measure the transverse profile of a rail head (or wheel profile) were reviewed and rejected because of limitations in accuracy due to the problem of referencing successive profiles to one another.
- . A new "floating" concept for on-site rail wear measurement was developed embodying:
 - use of the unworn regions of the rail head profile as reference points to eliminate referencing concerns;
 - digitizing profile measurements to permit automatic processing of results;
 - the matching of successive profiles.
- . The concept was tested through the generation and analysis of data derived by X-Y coordinate measurements taken from a blue print of a 136 lb. rail cross-section.
- . A software package was developed for data analysis and reporting.
- . The "floating" concept was further refined, design of hardware for rail head measurement and of software completed, measuring heads manufactured and the complete system tested.

Reports

"Concept of a Profilometer for Rail Wear Determination", by G. Izbinsky and G. Warshaw, Department of Research, Canadian Pacific Limited, December 1981.

CP Report No. - S655-81

TDC Report No. - TP3503

This report is also included as pages 154-186 of the Canadian Pacific

final report on Phase V, "Track/Train Dynamics Volume 3, 1982", TDC Report No. - TP4183E (no CP number).

"A Wheel/Rail Profilometer System, Vol. I and II", by G. Izbinsky, H. Sheekinger and H. Soares, Department of Research, Canadian Pacific Limited, February 1984.

CP Report No. - T-805-84

TDC Report No. TP5229E

Results/Findings

A rail profilometer system was developed with an accuracy of plus or minus .05 mm (with probability of 98%) for vertical wear and gauge face wear and less than 3 mm² for area of wear.

Task 33 - Conduct research on the design and performance of concrete track ties and fastenings

Performing Organization - CN Rail Research

TTD Contract Phase - II to IX incl.

Synopsis of Task Activities

Phase II

- . Two 39 ft. lengths of test track were constructed at the track structures test facility each consisting of 12 inches of crushed gravel subballast, 10 inch (minimum) depth below bottom of tie of crushed limestone ballast, 132 lb. rail, concrete ties with Pandrol fastenings. (One manufacturer's ties in one section and a second manufacturer's ties in the other).
- . Static loading tests using a 50-ton hydraulic jack were carried out to determine the lateral force-deformation characteristics of each panel (no consolidation of track, no vertical load), data analyzed and report prepared.
- . Initial measurements of track modulus were made.
- . A test frame for fatigue loading of concrete ties was ordered, received and installed in the Technical Centre's laboratory.

Phase III

- . Measurements were taken of frost heave that had occurred in the test panels over the preceding winter.
- . Test panels were instrumented.

- . Dynamic lateral loading tests of the test panels were carried out using a hydraulic ram to apply cyclic loading.
- . A 100-ton loaded car was cycled over the test panels for a total of 2 million gross tons and settlement measurements taken.
- . Track modulus measurements were taken of the test track under frozen conditions.
- . Static testing of specimen concrete ties from different manufacturers was carried out.
- . Preparations were made for measuring tie centre bending deflections in main track.

Phase IV

- . Track modulus measurements were made on the concrete tie installation in the test facility to check on recovery from frost heavings as the track thawed.
- . Comparison fatigue tests on four different manufacturers' concrete ties were initiated in the laboratory in order to evaluate centre bending fatigue life after initial cracking.
- . Field testing of centre bending deflection prototype transducers was carried out on the CN main line concrete tie installations at Kingston, Ontario.
- . Field measurements under unit trains were taken at three different sites on three different manufacturers' ties on the B.C. South Line.
- . Track modulus measurements were taken during freeze-up of the concrete test installation in the test facility, using two different methods for correlation purposes.

Phase V

- . A series of wheelset drop tests were conducted in the laboratory to develop instrumentation calibration techniques.
- . A large number of wheelset drop tests were conducted on the test track. Instrumentation problems were encountered.
- . Impact forces on the rail were measured by means of rail shear gauge circuits. The forces were also calculated from acceleration measurements taken on the wheelset.
- . Evaluation of rail seat pads were carried out through a number of wheelset drop tests on each of six different pads mounted on concrete

ties in the test track.

- . Measurements of frost heave and concrete tie center bending deflections were taken on the test track.
- . Measurements of concrete tie center bending deflections were taken on the Kingston, Albreda and Rivers Subdivisions.
- . Approximately 200 freeze-thaw cycles were applied to cracked concrete ties specimens in the cold chamber at the CN Research Centre.

Phase VI

- . Negative centre bend laboratory fatigue tests, on uncracked ties, commenced in Phase IV, were completed.
- . Positive and negative rail seat bend fatigue tests were carried out in the laboratory.
- . Inclined (20 degree) L/V rail seat fatigue tests were made, including rail fastener fatigue tests.
- . Through the use of an instrumented wheelset to overcome the instrumentation problems encountered during Phase V, successful wheelset drop tests on rail seat pads of varying stiffness were conducted at the test track and in the laboratory.
- . Field measurements of wheel loads, tie/rail seat loads, tie centre bending strains, rail seat bending strains, and rail web stresses were taken on concrete ties on frozen roadbed at Kingston, Ontario. Over 40 trains were recorded on digital magnetic tape. Data was taken at frequency content of up to 500 Hz in order to assess the effects of defective wheel impact loading on stiff roadbed.

Phase VII

- . Laboratory fatigue tests in three bending modes were conducted in order to establish the minimum bending moments at which fatigue "micro-cracks" would initiate and grow. (CN 60A tie)
- . Concrete tie bending deflection measurements on over 100 ties were taken on the Mountain and Prairie Regions and data analyzed.
- . Wheelset drop tests to evaluate concrete tie pad stiffness requirements were completed.
- . A computer program to statistically analyze measured concrete tie strains was written.
- . Fabrication of a fatigue test jig for evaluation of concrete tie pads

and insulators was completed in the Research shops, and initial start-up and debugging tests were conducted.

- . A considerable number of fatigue tests were conducted on various tie pads and insulators with the newly constructed fatigue test jig.
- . Bending fatigue tests were conducted on experimental CN 60A concrete ties manufactured with prestressed indented wire strand.
- . The design of the second generation (CN 60B) concrete tie was finalized.

Phase VIII

- . Inclined loading fatigue tests for the evaluation of tie pads and insulators were conducted. Major modifications to the test jig were made to achieve more consistent results.
- . Con-Force Costain Concrete Tie Co. Ltd., Edmonton, commenced regular longline production of the new CN60B ties. A visit was made to the plant to witness comparative testing of CN60A and CB60B ties. Many bending moment tests were run at the plant and data was forwarded to CN Research.
- . An in-depth analysis was made on results of CN60B tie bending tests conducted by Con-Force Costain in Edmonton. A dozen production-run CN60B ties were received at CN Labs for test evaluation.
- . Test plans were drawn up for the testing of CN60B ties and for evaluation of ties made with steel fibres.
- . A series of tests were run to evaluate the McKay Safelok (Australian) rail fastening system.
- . Physical property tests were conducted on new pad materials.
- . A series of bending moment tests were commenced on a strain gauged tie to develop moment-strain relationships.

Phase IX

- . The series of bending moment tests on a strain gauged tie were completed.
- . Laboratory physical property tests were conducted on two new pads for concrete ties.
- . Data from a series of laboratory tie bending tests on two strain gauged ties were analyzed and a preliminary report was written on the relationships between tie bending moment and concrete strain. This

report was forwarded to Canadian and British tie manufacturers for comment.

- Fatigue bending tests on the CN60B tie and on steel fibre reinforced ties were conducted. It was concluded that steel fibres did not significantly improve either the static or fatigue bending strength, although the resistance to impact breakage was improved.
- Dynamic gauge widening and strain measurements were taken on CN60A and CN60B ties on curves on the Albreda and Clearwater Subdivisions in British Columbia.
- Strain gauge measurements were taken on several concrete ties before and after saw-cutting in order to determine prestress wire bond development length.

Note: Concrete tie research is being continued under Phase X of the TDC/CN Cooperative Railway Research Program, still in progress as of the time of preparation of this summary report.

Reports

"Track Structures Test Facility, Test Report No. 1, Displacement of Newly Constructed Concrete Tie Track Under Static Lateral Load (Zero Vertical Load)" by J. F. Scott, CN Rail Research, January 1976.
CN Report No. - 131 TDC Report No. - none assigned

"Track Structures Test Facility, Test Report No. 2, Displacement of Newly Constructed Concrete Tie Track under Dynamic Lateral Load (Zero Vertical Load)" (Anon.), March 1977.
CN Report No. - 135 TDC Report No. - TP1330

"Track Structures Test Facility, Test Report No. 3, Performance of Concrete Tie Track Structure Under Repeated Low Speed Heavy Rolling Load" by A. Charenko and J. F. Scott, CN Rail Research, October 1977.
CN Report No. - 139 TDC Report No. - TP1331

"Use of Resilient Fastenings for Wood Ties as an Alternative to Concrete Ties - An Economic Comparison" by F. E. King, CN Rail Research, December 1976.
CN Report No. 142 TDC Report No. - none assigned

"Track Structures Test Facility, Progress Report No. 4, Concrete Tie Centre Bending Moments with Track Settlement and Frost Heave" by A. Charenko and J. F. Scott, CN Rail Research, November 1980.
CN Report No. - 162 TDC Report No. - TP2650

"Freeze-Thaw Tests on Concrete Ties" by C. R. Duggan, C. J. Dalton and J. F. Scott, CN Rail Research, July 1979.
CN Report No. - 155 TDC Report No. - TP2269

"Measurement of Concrete Tie Centre Bending Deflection Kingston, Albreda and Rivers Subdivisions, May 1978", by J. F. Scott and A. Charenko, CN Rail Research, September 1978.

CN Report No. - 151

TDC Report No. - TP2628

"Characteristics of the CN60A Concrete Cross Tie" by J. F. Scott, CN Rail Research, November 1980.

CN Report No. - 160

TDC Report No. - TP2647

"Impact Loading Measurements on CN60A Concrete Cross Ties - Progress Report" by J. F. Scott, CN Rail Research, November 1980.

CN Report No. - 163

TDC Report No. - TP2649

"Measurement of Concrete Tie Centre Bending Deflections Kingston, Albreda and Rivers Subdivisions July 1979", by A. Charenko and J. F. Scott, CN Rail Research, February 1980.

CN Report No. - 159

TDC Report No. - TP2583

"Measurement of Concrete Tie Centre Bending Deflections Albreda and Rivers Subdivisions September 1980" by A. Charenko and J. F. Scott, CN Rail Research, September 1981.

CN Report No. - 174

TDC Report No. - TP3346

"1980 Laboratory Research on Concrete Ties" by J. F. Scott, CN Rail Research, November 1981.

CN Report No. - 175

TDC Report No. - TP3585

Additional Reports Planned

"Concrete Ties - Measurement of Rail Impact Forces from Stationary Drop Tests and the Evaluation of Resilient Rail Seat Pads"

"Impact Loading Statistics on Concrete Ties"

"Laboratory Research on Concrete Ties, Period 1980 - 1983".

Results/Findings

- . Values were developed for the resistance of newly constructed concrete tie track to lateral movement when subjected to static or cyclic dynamic loading, and zero vertical load. (CN Reports No. - 131 and 135).
- . Information was developed on the performance of concrete ties and concrete tie track under repeated low speed heavy rolling load and the effect of frost heave and spring thaw and changes in track modulus. (CN Report No. - 139)
- . Data were developed on the comparative cost of strengthening the track

structure in curves by employing wood ties with special tie plates and Pandrol fastenings vs. by employing concrete ties with Pandrol fastenings.

(CN Report No. - 142)

Note: (The cost of this work was borne wholly by CN)

- . Measurements taken on the concrete tie test track showed that whereas concrete ties are normally subjected to negative centre bending moment on soft track, positive bending moment can sometimes result when track is frozen, and that frost action can cause very erratic tie to tie bending moment variations in both the positive and negative modes. The importance of good ballast, subballast and roadbed drainage in order to minimize the occurrence and initiation of uneven roadbed heaving (and consequent high centre bending moment in the tie) was amply demonstrated.
(CN Report No. - 162)
- . Laboratory freeze-thaw tests carried out on specimens cut from ties of four different manufacturers established that entrained air is an essential ingredient in concrete used in the manufacture of concrete ties for service on Canadian railways.
(CN Report No. - 155)
- . Centre bending deflection measurements made on CN60A concrete ties over a 4-year period on three geographically different CN territories revealed that, in general, deflections and hence stresses grow in magnitude as total tonnage carried increases. When the track is resurfaced centre bending deflections decrease. On the basis of these centre bending data and information derived from laboratory testing of concrete ties, it appeared that unless loss of acceptable track geometry requires track resurfacing at more frequent intervals, a 3 to 5-year resurfacing cycle will be adequate to keep tie centre bending moment levels sufficiently low to prevent tie cracking.

It was found that the variability of tie bending moments along a short section of track is considerable and may be related to a number of local conditions such as cut or fill section, type of subgrade, depth and type of ballast/subballast, location of water table etc. It was concluded that the concrete tie should have sufficient design strength to cope with the worst of these local conditions in order to avoid having to perform spot track maintenance to prevent localized tie cracking.
(CN Reports No. 151, 159 and 174.)
- . The comparative measurements taken on concrete ties at Kingston, Ont. under various conditions of frozen and unfrozen track and with both soft and stiff tie pads revealed that the highest tie loads and stresses resulted from the impact forces generated by defective wheels.
(CN Report No. 163.)
- . The very large number of laboratory and field test evaluations concerning concrete ties since the early 1970's was summarized and documented in a

single report prepared in 1980. Significant conclusions and recommendations derived from the work were presented. Recommendations include increasing the negative bending strength of the then standard CN60A tie and the continuance of research work to determine the optimum tie pad stiffness in order to attenuate the "spike" impact forces resulting from defective wheels.
(CN Report No. - 160)

. From the laboratory research work conducted on concrete ties during 1980 it was found that:

- In the laboratory, precracked concrete ties withstood many millions of bending fatigue loading cycles provided the applied bending moments were not greater than 1.2 times the static first crack bending moment levels. (Because of the harsh environment, it was felt such cracked ties would not fare as well in track).
- Initially uncracked concrete ties developed fatigue micro-cracks at moment levels significantly below the static first crack moment levels. The design of concrete ties should be based upon fatigue strength rather than static cracking strength.
- The criteria which should be adopted in calculating conservative theoretical strengths for concrete ties are:
 - (a) Static cracking moment - 30% prestress loss
 - concrete cracks at 800 psi tension
 - (b) Fatigue cracking moment- 30% prestress loss
 - zero tensile strength in concrete
- Anything which will enhance the tensile strength of concrete could greatly improve the bending strength of concrete ties. (This could significantly alter the design of concrete ties in the future).
- On the basis of preliminary laboratory tests on experimental CN60B ties the negative bending strength of the CN60B ties is higher than that of the CN60A ties.
- The stronger CN60B tie is stiffer than the CN60A tie, having only 78% of the center deflection under similar moment levels.
- CN60A ties made with indented wire strand are weaker in rail seat positive bending than regular ties made with single indented wires. Shear cracking on the strand ties was more pronounced than on the regular ties.
- Rail longitudinal restraint varied widely depending upon type

of rail pads used in the fastening system. With soft styrene butadiene (SBR) pads, an average restraining force of 2774 lbs. was developed, while with hard ethyl vinyl acetate (EVA) pads, the average restraining force was 921 lbs. (Difficulties could arise in anchoring CWR in territories where harder tie pad materials are used).

- Longitudinal rail displacement fatigue tests on the rail fastening system produced minimal wear on pads and insulators but produced fatigue failures on 17 rail clips. (The test was not representative of field conditions where pads and insulators failed but clips did not. Pads and insulators apparently do not fail through the mechanism of rail longitudinal movements).
- Preliminary inclined loading fatigue tests on the rail fastening system produced pad and insulator failures. (It appeared that this test procedure may be useful in evaluating the fatigue service life of various pad and insulator types, subject to first determining the best loading magnitudes and angles through additional tests).
(CN Report No. - 175)

Task 34 - Conduct studies related to the properties of ballast and the strength and stability of the ballast system.

Performing Organization - CN Rail Research

TTD Contract Phase - I, II, III, VII, VIII

Synopsis of Task Activities

Phase I

- . Freeze-thaw tests were carried out on selected samples of crushed rock ballast originating from a field test on the Sorel Subdivision. (This work was underway at CN Research prior to the start of the CN/TDC cooperative program). A total of 300 freeze-thaw cycles were completed.
- . A direct shear machine was designed and constructed to enable relating the strength of the ballast system with changes in particle shape, grading and initial density. Tests were conducted to relate change in strength with variations in these three properties.
- . Tests were conducted to relate achievable ballast density to variations in vibration frequency, vibration time and surcharge loads.

Phase II

- . Regression analysis (linear and non-linear) was carried out on the freeze-thaw breakdown results of ten different ballast materials to correlate the measured breakdown at different numbers of freeze-thaw cycles (50, 100, 200, 300 cycles) with the results of the standard laboratory soundness and absorption tests.
- . Forty-five direct shear tests were carried out on crushed limestone ballast from a Montreal quarry to evaluate the increase in lateral shearing resistance that can be effected by particle shape, initial density, etc.

Phase III

- . A series of lateral "shear box" tests were undertaken on crushed rock ballast (Montreal Limestone) to measure the improved shearing strength and lateral resistance which can be developed by altered grading, and initial density (i.e., compaction) of the ballast. Tests were carried out at two different gradings, three different initial densities, and three different surcharge pressures.

Phase VII

- . Repairs and modifications were made to the direct shear machine.
- . Shear tests were run on materials of varying density and particle shape.

Phase VIII

- . A final series of shear tests were conducted.

Reports

"Petrographic Study of Ballasts" by Jean Berard Ph.D., Ecole Polytechnique, Sept. 10, 1973.

CN Report No. - 130

TDC Report No. - none assigned

"Field Durability Tests on Ballast Samples as a Guide to the Significance of the Specification Requirements", by C. J. Dalton, CN Rail Research, January 1973.

CN Report No. - 110

TDC Report No. - none assigned

Note: The work discussed in the above two reports was carried out prior to the commencement of Phase I. The reports are referenced here because the work is closely related to the task requirement.

"Crushed Rock Ballast Densification Tests" by N. Caldwell and C. J. Dalton, CN Rail Research, March 1974.

CN Report No. - 118

TDC Report No. - none assigned

"Freeze-Thaw Tests on Ten Ballast Samples" by C. J. Dalton, CN Rail Research, June 1976.

CN Report No. - 133

TDC Report No. - none assigned

"Strength Tests on Crushed Rock Ballast" by C. J. Dalton, CN Rail Research, April 1977.

CN Report No. - 138

TDC Report No. - TP984

Additional Reports in Preparation or Planned

"Preliminary Evaluation of the Effect of Particle Shape and Grading on Ballast Strength".

"Strength and Stability of Ballast System".

Results/Findings

. Information was obtained regarding:

- value of petrographic studies to aid in the evaluation of rock proposed to be used for track ballast;
- the suitability of rock from various specific sources for use as track ballast.
(CN Report No. - 130)

. Information was obtained regarding the relationship between the results of standard laboratory approval tests for railway ballast and the service performance of that ballast. (CN Report No. 110)

. Data were developed on densification of railway ballast by the vibration method in the lower frequency range of vibration (15-30Z). (CN Report No. 118)

. Data were obtained on freeze-thaw loss of crushed rock and slag ballast samples. Information on the relationship (or lack of relationship) between freeze-thaw loss and the absorption and sulphate tests was obtained as well as on the relationship between freeze-thaw loss and petrographic evaluation. (CN Report No. - 133)

. It was found from laboratory testing that:

- ballast compaction increased density up to 28% and shear strength up to 300%.
- at 0.125" lateral displacement the useable strength (i.e. the resistance to shear due to friction generated by sliding.

rolling or interlocking between particles) has been developed. Beyond 0.125" lateral displacement occurs with small increase in strength.

- an increase in vertical loading causes an increase in absolute shear strength.
 - vibration increases the shear strength of coarsely graded ballast to a greater extent than it does the shear strength of a more finely graded ballast.
- . These and other findings relating to ballast strength are important in the development of improved ballast specifications and the achievement of stronger railway track.
(CN Report No. - 138)

Task 35 - Develop a machine to mechanize trowelling operations.

Performing Organization - CN Rail Research

TTD Contract Phase - I

Synopsis of Task Activities

Note: In some circumstances, the most economical and satisfactory method of spot-surfacing track is by trowelling. With this method, the tie ends are raised slightly by jacking and a small amount of fine crushed stone placed between the tie and the tie bed under the rail using a long-bladed trowel, so that when the tie ends are lowered the top of rail is restored to a uniform profile. A major advantage of this method of surfacing is that the well-compacted tie bed is not disturbed. However, the method has a high labour content, the largest portion of which is in moving the ballast away from the tie ends to enable placing the trowelling stone, and then replacing the ballast at the tie ends following that operation.

The purpose of this task was to mechanize this most labour intensive portion of the trowelling operation.

- . Modifications were made to a standard Kershaw Ballast Regulator, Model EP - 135 to enable plowing out and replacing ballast at the ends of ties and the modified unit tested.
- . Additional modifications were made to further reduce the manual input to the operation and further testing carried out to confirm feasibility.

Reports

"Modification to a Standard Ballast Regulator as an Aid to Trowelling"
by W. J. Wood, W. Bowler and C. J. Dalton, CN Rail Research, (no date).
CN Report No. - 117 TDC Report No. none assigned

Results/Findings

- . An ability to reduce labour costs for trowelling in certain territories was developed. The use of the modified machine, however, requires track occupancy which is not required if the operation is accomplished wholly manually. Hence its use on high tonnage track (where most trowelling is normally done) is not generally favoured because of the possibility of delays to trains.

Task 36 - Conduct laboratory and field investigations of subgrade soils to enable accurate prediction of optimum subballast thickness requirements.

Performing Organization - CN Rail Research and McGill University
Geotechnical Research Centre (Subcontractor)

TTD Contract Phase - VI, VII, VIII and IX

Synopsis of Task Activities

Phase VI

- . Published literature on similar research work conducted by British Rail was reviewed.
- . An instrumentation and hardware system was assembled to measure tie loads and deflections, ballast or subballast/subgrade interface deflections and variations in subgrade porewater pressure during train passage.
- . Test sites for field measurements were selected at 13 different locations in the Edmonton area.
- . The instrumentation was installed and measurements taken at each of the test sites successively.
- . Dynamic triaxial testing was conducted on samples of the Edmonton clay by the sub-contractor, McGill University Geotechnical Research centre.

Phase VII

- . Three new test sites were established in the Edmonton area and one at L'Assomption, Que.
- . Instrumentation to measure dynamic track deflection and variations in subgrade porewater pressure at the new sites was assembled and installed and measurements taken successively at each of the 3 new Edmonton sites, and at L'Assomption.
- . Laboratory soils tests of subgrade soil samples and analysis of test data were continued at both CN Research and McGill Geotechnical Centre.

Phase VIII

- . Measurements of dynamic track loading and deflection and subgrade deflection were taken at intervals at certain of the Edmonton sites and the L'Assomption site. Frost heave measurements were also taken at the L'Assomption site.
- . McGill University Geotechnical Centre continued their soils testing and analysis program.

Phase IX

- . Track settlement measurements were taken at the Edmonton and L'Assomption sites on a regular basis.
- . McGill University continued their soils testing and analysis program.

Note: This work is continuing under Phase X of the TDC/CN Cooperative Railway Research Program, still in progress as of the time of preparation of this summary report.

Reports

"Dynamic Triaxial Testing Program, Present Status" by D. E. Sheeran, Geotechnical Research Centre, McGill University, July 15, 1979.

CN Report No. - None assigned

TDC Report No. - Not yet assigned

"Predicting Requirements for Subballast Thickness, Progress Report No. 1, Measurements of Track Loads and Deflections Edmonton, Alberta, May 1979" by C. J. Dalton and J. F. Scott, CN Rail Research, February 1980.

CN Report No. - 158

TDC Report No. - TP2584

"Prediction of Long Term Track Subgrade Settlement Due to Cyclic Wheel Loading" by D. E. Sheeran, H. H. Elmagloul and E. A. Fattah, Geotechnical Research Centre, McGill University, November 1980.

CN Report No. - 164

TDC Report No. - TP2648

"Predicting Requirements for Subballast Thickness, Progress Report No. 2, Measurement of Track Loads and Deflections Edmonton, Alberta, June 1980, L'Assomption, Quebec, August, 1980", by C. J. Dalton and J. F. Scott, CN Rail Research, April 1981.

CN Report No. - 166

TDC Report No. - TP2987

"An interim Report for the Design of Ballast Thickness Under Adverse Conditions", by D. E. Sheeran and R. Jayarman, Geotechnical Research Centre, McGill University, September 1981.

CN Report No. - 177

TDC Report No. - TP3766E

"Predicting Requirements for Subballast Thickness, Progress Report No. 3, Measurements of Railroad Track Loads, Roadbed Dynamic Deflections and Settlements" by J. F. Scott, CN Rail Research, March 1983.

CN Report No. - 179

TDC Report No. - TP4350E.

Additional Reports in Preparation or Planned

"Laboratory Investigation of Long Term Railroad Track Subgrade Settlement Due to Cyclic Loading".

"Design Requirements for Railroad Track Subballast Thickness - Summary Report".

Results/Findings

- . A method was developed to predict track surface settlements depending on type of subgrade soil, depth of subballast, magnitude of wheel loading and number of load cycles.
- . Charts depicting annual subgrade settlement under varying load conditions and depths of subballast were developed and as well, a specific design method employing charts to predict total settlement under adverse conditions.
- . Optimum subballast thickness requirements for various subgrade conditions and traffic conditions were developed.

Note: The final results of this work will not be available until the completion of the Phase X work.

Task 37 - Conduct investigations on the alleviation of frost heaving of railway track roadbed by chemical treatment.

Performing Organization - McGill University Geotechnical Research Centre on behalf of and in cooperation with CN Rail Research.

TTD Contract Phase - IV

Synopsis of Task Activities

- . Two field test sites were established - one on a CN industrial spur track near Dorval Que., and one on the CN Main line near Coteau, Que.
- . The test sites were instrumented with thermocouples, tensiometers, electrical conductivity probes and heave plates (heave plate - a length of 3/8" diameter rod welded perpendicularly to a small steel base plate).
- . Individual portions of the test site were treated with chemical systems consisting of sodium chloride followed by sodium silicate, calcium chloride followed by sodium carbonate, ferric chloride.
- . Precise levels were taken at regular intervals to observe heave on both treated and untreated portions of the test site.
- . Conductivity measurements were made at regular intervals to help pinpoint the salt concentrations in the soil profile.
- . Tensiometer and thermocouple readings were taken at regular intervals to monitor the position of the frozen ground line.
- . Soil samples were taken at intervals and chemical analyses made.

Reports

"Performance of Frost Heave Modifying Chemical Additives at the CN Dorval Test Site" by D. E. Sheeran and R. N. Yong, Geotechnical Research Centre, McGill University, October 1978.

CN Report No. - 149

TDC Report No. - TP1814

McGill Geotechnical Research Centre Report No. FHTD-VIII.

Other valuable information on this work is contained in the following McGill University Geotechnical Research Centre Reports:

"Alleviation of Detrimental Frost Heaving of Soils by Chemical Treatment" by Raymond N. Yong and Donald E. Sheeran, January 1978.

McGill Research Report No. - None assigned. TDC Report No. - TP1408

"The use of Precipitants to Decrease the Rate of Migration of Frost Heave Modifying Additives" by Raymond N. Yong and Donald E. Sheeran, Geotechnical Research Centre, McGill University, April 1976.

McGill Research Report No. - FHTD-VI

TDC Report No. - None assigned.

Results/Findings

- . A much increased understanding was gained of the mechanism by which the frost-heaving of railroad track subgrade is reduced by the addition of chemicals to the track surface.
- . It was found that sodium chloride, calcium chloride and ferric chloride were about equally effective in reducing total heave but because of the high cost and difficult handling procedures for ferric chloride, it is the least attractive.
- . Calcium chloride appears to enhance a thaw-subsidence problem induced by dynamic vehicle loads at the time of thaw.
- . It was determined that the effect of the salt in controlling the forces leading to ice lensing is more important than the effect of the salt in reducing the freezing temperature of the soil.
- . Information was obtained as to the value of adding a second chemical (a "void plugger") to prolong the effectiveness of the initial chemical treatment by reducing the migration rate of the first chemical.

4.4 Bridges

Task 38 - Investigate the effects of train passage on the superstructure and substructure of bridges.

Performing Organization - Department of Research, Canadian Pacific Limited, with participation by the National Research Council of Canada.

TTD Contract Phase - I and II

Synopsis of Task Activities

Phase I

- . Steel bridges at mileages 1.7 and 31.4 on the CP Rail Shuswap Subdivision were instrumented employing strain gauges installed on certain of the steel members of the various spans, and accelerometers installed on the piers and abutments. The purpose of the strain gauges was to enable derivation of shear and bending stresses occurring in the members during passage of trains. The purpose of the accelerometers was to enable evaluation of their use as a method of measuring pier displacements indirectly. Instrument output was recorded under passage of mixed freight trains and various unit trains over a range of speeds. Strain gauge signals were converted to stresses and accelerometer signals to displacement.
- . Field tests were conducted to evaluate the practicability and accuracy of laser technology for the measurement of lateral and vertical displacement of bridge piers due to train loading. The tests were conducted on the CP Rail Gatineau River Bridge at Mileage 115.9 Lachute Subdivision and the Nipigon River Bridge at Mileage 62.4 Nipigon Subdivision. The laser used was an He-Ne laser with a power rating of 4 mW. The laser beam was trained on a quadrant photocell detector firmly fastened to the bridge pier to enable measurement of any relative movement between it and the highly stable laser light beam during passage of a train across the bridge.
- . Following the discovery of cracks in the stringer webs of several bridges in late 1975, a test program was undertaken on the CP Rail bridge at mileage 51.5 on the Windermere Subdivision, to measure stress levels at various locations on the stringers. Several stringers on the bridge were strain gauged in early May 1976 and stress levels recorded during passage of trains comprised of both loaded and empty cars and operated at various speeds.

Reports

"Track/Train Dynamics Report #2, Testing of Bridges at Mileages 1.7 and 31.4 Shuswap Subdivision", by Department of Research, Canadian Pacific

Limited, October 1973.
CP Report No. - S460-73

TDC Report No. - None assigned

This report is also included as Section B of the Canadian Pacific final report on Phase I - "Track/Train Dynamics Phase I", March 1975 (not numbered).

"Track/Train Dynamics Report #5, Measurements of Bridge Pier Displacement Using Laser Technology", by J. Kalousek and R. Gonsalves, Department of Technical Research, Canadian Pacific Limited, March 1975.

CP Report No. - S491-75

TDC Report No. - None assigned

This report is also included as Section F of the Canadian Pacific final report on Phase I - "Track/Train Dynamics Phase I", March 1975 (not numbered).

"Stringer Stress Measurements on Bridge, Mile 51.5 Windermere Subdivision", by J. Kalousek and A. E. Bethune, Department of Research, Canadian Pacific Limited, (no date).

This report was not published separately but is included as pages 362-398 of the Canadian Pacific final report on Phase II, "Track/Train Dynamics Vol. 1, 1978". TDC Report No. - TP4576E (no CP number)

Results/Findings

- . Information was obtained on actual stress levels in steel bridge members subjected to various levels of train loading at various speeds.
- . It was found that pier and abutment displacements due to train loadings could not be measured using accelerometers.
(CP Report No. - S460-73)
- . The use of laser technology as a simple and reliable means of accurately determining small displacements of large structural members such as bridge piers was demonstrated. It was found though, that the accuracy of the measurements is influenced by atmosphere and local conditions.
(CP Report No. - S491-75)
- . Probable factors leading to crack initiation in webs of stringers in railway bridges were identified and measures to prevent crack initiation developed.
(TDC Report No. 4576E. pp 362-398)

4.5 Vehicle and Train Dynamics

Task 39 - Investigate the vibrational characteristics of freight cars

Performing Organization - Department of Research, Canadian Pacific Limited with participation by the National Research Council of Canada.

TDC Contract Phase - I

Synopsis of Task Activities

. Seven different types were investigated as follows:

- LPG Tank
- 100-ton Gov't of Canada Grain (with centre plate extension (C-PEP))
- 100-ton Covered Hopper (NAHX)
- 100-ton Covered Hopper (CP)
- 80-ton Open Top Triple Cross Hopper
- 89 ft. Container
- 100-ton Bathtub Coal (with and without C-PEP)

The tests were conducted at Coquitlam Yard, Vancouver, in both loaded and unloaded condition.

- . The cars were excited in their bounce and pitch modes by running them at low speed over wedges, located under each wheel on both trucks. Excitation of the car occurred when it dropped off the wedge. Vibration frequency was measured with accelerometers mounted on the car centreline, one at each end. Damping in both of the modes of vibration was determined from the rate of decay of the vibration in each of the modes.
- . The cars were excited in their roll and twist modes of vibration by jacking on a corner or side sill of the car using a hydraulic jack. The frequency and stroke of the force application were continuously variable, and the forcing frequency was swept through a range until the resonant frequency of the car for the mode in question was found. At this point, the jacking force was removed and the consequent decay of the car vibration was recorded. In this manner, both the resonant frequency and the rate of damping were determined for the mode of vibration in question. Two accelerometers were used to record the vibration at the corners along one side of the car.
- . In the case of the 89' light container flat car, the flex mode of vibration of the car center sill was also determined. This was done by having a man jump once on the center sill of the car and measuring the resulting oscillations with an accelerometer.
- . To determine the effect of the roadbed stiffness, the bounce and pitch tests were repeated for two of the cars in a shop with a concrete floor.

Reports

"Track/Train Dynamics, Report #1, Natural Frequencies of Vibration, Heavy Freight Cars" by Department of Research, Canadian Pacific Limited, (author's name not given), June 1973.

CP Report No. - S456-73

TDC Report No. - none assigned

This report is also included as Section A of the Canadian Pacific final report on Phase I - "Track/Train Dynamics, Phase I", March 1975 (not numbered).

Results/Findings

- . The natural frequencies of several types of cars, in bounce, pitch, roll and twist were measured and the effect of C-PEP side bearings on the vibrational properties of the bathtub coal cars determined.
- . The information derived from the tests has application in the general area of the "rock-and-roll" phenomenon and in studies of bridge and other roadbed structures.

Task 40 - Investigate the dynamic effects of unsprung weight on track loadings.

Performing Organization - Department of Research, Canadian Pacific Limited with participation by personnel of the Railway Laboratory of the National Research Council.

TTD Contract Phase - II

Synopsis of Task Activities

- . An extensive literature search was carried out.
- . To assist in the vertical dynamic evaluation of various properties of track structures and rolling stock, a computer program, originally developed in the USSR, was rewritten and modified.
- . Power spectral densities of track irregularities from various countries were compiled for reference.
- . The influence of various factors, including unsprung weight, on vertical track forces was examined theoretically.
- . Dynamic measurements of track irregularities were carried out on the CP Rail Thompson Subdivision. The unfiltered signals from the instrumentation which measured vertical profile of the track were recorded under light and heavy axle loading while operating over jointed

and continuous welded rail, tangent and curved track and corrugated rail. Data were analyzed. Power spectral density plots of vertical accelerations were obtained for corrugated, welded and jointed rail track.

- . Further measurement of track irregularities at speeds up to 70 mph were carried out on CP mainline between Montreal and Ottawa using the CP Track Recorder Car. In addition to the existing instrumentation on the Track Recorder Car, two existing bearing adapter plates on the Car were modified and instrumented to function as load cells. The bearing adapter plate load cells provided a means of recording, simultaneously, the vertical acceleration of the wheelset and the force on the primary suspension. Data were analyzed. Power spectral densities of vertical accelerations were obtained. Wheel/rail forces were evaluated by suitably combining the acceleration and force signals.
- . The power spectral density plots of track irregularities and wheel/rail forces were reviewed in detail and classified according to type of track, vehicle and speed. It was found that corrugated rail is readily identified by definite wavelengths. In addition, car body bounce shows clearly on the wheel/rail force spectrum of the Track Recorder Car.
- . The Russian computer program for vertical dynamics of railway vehicles was simplified to reproduce a simulation of a Metroliner operating on Class 6 track in order to compare results with data obtained previously by Battelle Laboratories. Using the same input data from the Metroliner, the output of the Russian program was found to be identical to the results obtained by Battelle Laboratories, thus establishing a good degree of confidence in the Russian program.
- . Vertical wheel/rail forces generated by the track recorder car were simulated using the modified Russian computer program. The inputs to the program were the track recorder car specifications, the measured vertical profile of a section of continuous welded rail and other assumed track parameters such as stiffness and damping. The resulting wheel/rail forces predicted by the computer were then compared with actual measurements of wheel/rail force carried out over the same section of continuous welded rail.

Reports

"Effect of Unsprung Weight on Vertical Track Dynamics", by J. Robert, Department of Research, Canadian Pacific Limited (Interim Report)
CP Report No. - None assigned. TDC Report No. - TP1224.

This report is also included as pages 309-322 of the Canadian Pacific final report on Phase II, "Track/Train Dynamics Vol. I, 1978".
TDC Report No. - TP4576E (no CP number).

Results/Findings

A methodology was developed to enable investigating the influence of various equipment and track parameters upon dynamic force levels.

Task 41 - Develop instrumented freight car wheelsets

Performing Organization - CN Rail Research

TTD Contract Phase - I, II, III and IV

Synopsis of Task Activities

Phase I

- . A wheelset calibration rig and its hydraulic loading system was fabricated and checked out.
- . The data acquisition system was programmed and debugged.
- . One wheel disc of a 36" diam. 100-ton capacity wheelset was strain-gauged with a series of 14 gauges.
- . Over 3000 strain gauge readings were taken under a different combinations of vertical and lateral loads.
- . An axle-mounted telemetry transmitter housing and transmitting aerial system was designed and built.
- . Calibration of strain bridges was completed and a jig for spinning the wheelset to apply centrifugal strain to the wheel plate was fabricated.

Phase II

- . Centrifugal spin-up tests were carried out on the experimental instrumented wheelset.
- . The wheelset was installed under a loaded 100-ton capacity cylindrical hopper car and two shakedown runs made. It was also run on the 5 degree test curve to compare its output against the other track based measurements and independent measurements of wheel/rail reaction forces. The tests showed the need for modifications.
- . A finite element computer program was developed to assist with the work.

Phase III

- . A proposed improved strain gauge pattern was checked out using the finite element analysis technique.
- . Strain search tests were completed for the new strain gauge pattern and strain measurements progressed to determine the optimum radial location for gauge application.

Phase IV

- . Static loading calibration of the second strain gauged wheel disc on the AAR profile 100-ton instrumented wheelset was completed and data results plotted.
- . Dynamic spin-up tests for centrifugal strain calibration were carried out using the strain gauge telemetry equipment to pick up the strain signals from the rotating wheelset. This completed the calibration of the wheelset and final waterproofing of the strain gauges was then carried out.
- . The 100-ton capacity AAR contour instrumented wheelset was field tested in curves under a loaded car at slow speed in Montreal Yard with both wheel discs sensing wheel/rail forces. Operating problems with the telemetry system were encountered, resulting in intermittent loss of signals.
- . Modifications were made and additional field tests made. Analysis of test results indicated continuing signal problems.
- . A slip ring system was acquired for trial in order to evaluate the fidelity of data transmission with this alternate equipment.
- . A 100-ton freight wheelset with machined service worn profile wheels was acquired and layed out for strain gauging.
- . The 100-ton freight wheelset with worn profile was machined (i.e. axle drilled) to accept slip ring assemblies. The slip ring attachment hardware was also machined. Search strain gauges were applied for both the vertical and lateral strain bridges on both wheel discs. Strain search loadings in the wheelset calibrating rig were carried out.

Note: No additional work on this subject was carried out within the TDC/CN Rail cooperative Track/Train Dynamics Program.

Reports

No final report was prepared on this work.

Results/Findings

Development of a validated methodology for instrumenting freight car (and locomotive) wheelsets. Two instrumented 100-ton capacity freight car wheelsets were produced and tested.

Task 42 - Develop a train handling recorder

Performing Organization - CN Rail Research

TTD Contract Phase - I, II, III and IV

Synopsis of Task Activities

Phase I

- . Five previously ordered recorder units, one playback unit and one test set were supplied. (The recorders were specified to monitor the last 14 hours of current data during which the locomotive was moving at speeds exceeding 2 mph). Eight channels of analog data were to be taken - speed, throttle/dynamic brake settings, train-line pressure, locomotive brake cylinder pressure, locomotive truck brake cylinder pressure, locomotive acceleration, traction motor current, elapsed time of day, locomotive truck rotation. Also 8 channels of binary data - 1/10-mile distance count, forward or reverse movement, dynamic brake or motoring, wheelslip, horn, bell, location of emergency brake applications, tape synchronization error. Data retrieval was by data playback unit with a speed-up of about 7 to 1.
- . A train handling recorder and instrumentation harness was installed on an SD-40 unit. Various problems with the instruments were encountered and modifications were made by the manufacturer. It was also found that the mounting location yielded vibration levels in excess of the manufacturer's requirements and a new vibration isolation mounting was designed and fabricated by CN. Tests of the improved mount on a GF-30 locomotive were made. Various problems were overcome and the mount was deemed satisfactory.
- . Using the improved mount, a recorder was mounted on a GF-30 locomotive road number 5129.

Phase II

- . After 3 months unattended service on CN locomotive 5129 the recorder was inspected. Various deficiencies were found. The recorder was removed

and a replacement installed. After another 3 1/2 months, the second unit was removed for inspection. Again deficiencies were found. All units were returned to the manufacturer for thorough inspection and failure analysis.

- . Alternative commercial recorder transport systems were investigated.

Phase III

- . An alternate recorder was ordered and received and the work of interfacing it with the locomotive transducer harness was progressed.

Phase IV

- . Further work was carried out on interfacing the alternate recorder's control circuits with the locomotive transducer harness.

Note: Because of other priorities and constraints, it was decided in conjunction with TDC to reschedule this task to a subsequent phase; however, no further work on it was undertaken under these cooperative contracts.

Reports

No report was prepared on this work.

Results/Findings

It was concluded that the mechanical and electrical design of these initial recorders (originally intended for aircraft service) was not compatible with the severe environment present on a railway locomotive. Subsequently, more compatible units have been developed commercially and are in service on both CN and other North American railways. Undoubtedly, this early work contributed significantly to these developments.

4.6 Rail/Wheel Interface

Task 43 - Develop experimental rail/wheel wear apparatus.

Performing Organization - The Western Laboratory of the Division of Mechanical Engineering of the National Research Council with financial participation by the Department of Research, Canadian Pacific Limited and the Association of American Railroads (and the Transportation Development Centre of Transport Canada).

TTD Contract Phase - III and IV

Synopsis of Task Activities

Phase III

- . Initial design was completed for a laboratory rolling test apparatus to simulate the interaction between wheelset and rails in curves or on tangent track and, as well, the data acquisition system for the apparatus.
- . Most of the mechanical components for the laboratory apparatus were purchased, or manufactured in the Western Laboratory workshop of NRC. Rail and wheel sample material was donated by several railroads and supply companies.
- . The minicomputer modules, needed to interface the apparatus with the microprocessor were ordered.

Phase IV

- . The apparatus was assembled and tested and the electronic interface system installed.
- . Wheel and rail discs manufactured from different steel metallurgies were produced by the Department of Energy Mines and Resources of Canada and their testing commenced.
- . A "Master Operations Program" was developed to simulate a wear history throughout 1 million gross tons.

Reports

"Experimental Rail/Wheel Wear Apparatus" by J. Kalousek, National Research Council.

This is a progress report on the development of the apparatus. It was not published separately but is included as pages 55-57 of the Canadian Pacific final report on Phase III, "Final Report, Track/Train Dynamics

Program, Phase III, 1st October 1978 - 15th May 1979".

CN Report No. S601-79

TDC Report No. TP2437

Results/Findings

An experimental apparatus to enable the carrying out of a wide variety of laboratory rail/wheel wear tests was designed and made operational at the Vancouver Western Laboratory of NRC. Subsequently, the apparatus was further enhanced and valuable use of it is being made in the current joint NRC/TDC/AAR research program aimed at developing a wear and fatigue model for railway rail.

Task 44 - Conduct analytical studies of steady state curving and dynamic behaviour of wheel/rail systems.

Performing Organization - Department of Research, Canadian Pacific Limited, with participation by the National Research Council of Canada.

TTD Contract Phase - V

Synopsis of Task Activities

- . Various theories of rolling contact were investigated. Two computer programs were written and an additional two were obtained from their authors. The theories and corresponding programs were evaluated for their applicability to the problems of typical wheel/rail and wheel/roller systems.
- . To obtain information on vehicle behaviour, work was done on both steady curving and dynamic truck models. The curving model was completed, and development of the dynamic model commenced.
- . Using results from tests conducted on the NRCC rail/wheel wear apparatus in Vancouver and the above-mentioned rolling contact programs, work was done to obtain a correlation between experiment and theory based on the nature of the material behaviour within the contact zone.

Note: This work was continued by Canadian Pacific under cooperative contract OSD82-00162 with TDC (Phase VI).

Reports

"Analytical Studies of the Rail-Wheel System: An Overview of Applications of Rolling Contact Theory", Department of Research, Canadian Pacific Limited.

This report was not published separately but is included as pages 187 - 192 of the Canadian Pacific final report on Phase V, "Track/Train Dynamics Volume 3, 1982". TDC Report No. TP4183E (no CP number).

Results/Findings

- . An improved understanding was gained of the nature of wheel/rail contact mechanics and related computer simulation programs developed.

5. IMPACTS OF THE TTD RESEARCH PROGRAM ON CANADIAN RAILWAY
OPERATIONS AND RESEARCH ACTIVITIES

In conformance with the contract Terms of Reference, discussions were held with certain of the CP and CN operating and research officers for the purpose of identifying the principal impacts (benefits) of the research program on Canadian railway operations and research activities. The outcome of those discussions is summarized in Table 3 on the following pages of this Section.

It is evident that the program will also generate valuable secondary benefits because of the experience gained by both railway researchers and the various other researchers from outside industry, the university community and government who participated directly in the work. The significant research experience gained thereby can be expected to result not only in long term benefit to the Canadian railway industry but also can be expected to have a positive impact throughout a much broader spectrum of the overall Canadian economy.

TABLE 3

Impacts of The Canadian Track/Train Dynamics Research Program on
Canadian Railway Operations And Research Activities

<u>Outcome of Research</u>	<u>Benefit</u>	<u>Basis for Benefit</u>
<u>Locomotive Trucks</u>		
1. Identification of 3-axle truck modifications to improve curving performance (Tasks 1 and 2)	Reduction in track maintenance costs	Reduction in 3-axle locomotive curving forces and consequent reduction in rail wear and other track damage
	Reduction in loss of traffic capacity	Reduction in train delays caused by track maintenance and in derailments caused by excessive curving forces
	Increase in locomotive utilization	Elimination of special speed restrictions on curves, (speed restrictions placed (on CN) in order to reduce curving forces to acceptable limits)
	Enhanced research capability	Availability of computer program, developed during investigation, for further research

<u>Outcome of Research</u>	<u>Benefit</u>	<u>Basis for Benefit</u>
<u>Freight Car Trucks and Wheels</u>		
2. Improved design of instrumented base plates (tie plates) (Task 3)	Increased quality and reduced cost of railway research	Increased accuracy and reliability of rail/tie force measurements under dynamic wheel loading with consequent improved ability to evaluate the curving performance of railway rolling stock
3. Instrumentation to measure wheel/rail vertical contact force (Task 3)	Reduction in track, bridge and freight car maintenance costs	Much-improved ability to identify overloaded cars, by means of a coupled-in-motion overloaded car detector developed subsequently, utilizing the wheel/rail contact force measurement instrumentation
4. Enhanced computer programs to calculate freight car truck curving forces (Tasks 5 and 15)	Reduced cost of research	Increased ability to evaluate performance of various truck designs by computer analysis with consequent reduced requirement for costly field tests.
5. Development and widespread adoption of modified profile for freight car and locomotive wheels (Tasks 6, 7 & 8)	Reduction in track maintenance cost	Reduction in vehicle curving forces and consequent reduction in rail wear and other track damage and derailments

<u>Outcome of Research</u>	<u>Benefit</u>	<u>Basis for Benefit</u>
	Reduction in loss of traffic capacity	Reduction in train delays caused by track maintenance and in derailments caused by excessive curving forces
	Reduction in wheel maintenance cost	Increase in operated mileage between wheelset removals due to reduced rate of flange and tread wear. Reduction in metal loss during reprofiling of wheels
	Reduction in locomotive fuel consumption	Reduction in rolling resistance in curves
	Increased quality of railway research	Enhanced ability to evaluate truck curving characteristics accurately
6. Development of laser equipment to accurately measure wheelset angle-of-attack (Task 9)	Useful information, for maintenance purposes, on condition of freight car trucks	N/A
7. Data on angle-of-attack of wheelsets on freight cars in regular train consists (Task 10)	*Reduction in track maintenance cost *Reduction in numbers of derailments	Reduction in freight car curving forces and increase in vehicle stability at high speed when empty, with consequent reduction in rail wear and other track damage
8. Design and validation (through extended service testing) of retrofit components for standard 3-piece freight car trucks to provide "self-steering" capability (Tasks 11 and 12)		

<u>Outcome of Research</u>	<u>Benefit</u>	<u>Basis for Benefit</u>
9. Data on the performance of various "new generation" freight car trucks and their effect on rail wear, wheel wear, other track maintenance costs and potential energy savings (Tasks 13, 14 and 16)		Reduction in train delays caused by track maintenance and derailments, due to reduced curving forces.
	*Reduction in locomotive fuel consumption	Reduced freight car rolling resistance in curved track
	*Reduction in wheel maintenance cost	Increase in operated mileage between wheelset removals due to reduced rate of flange and tread wear. Reduction in metal loss during reprofiling of wheels
10. Development of an improved wheel profilometer (Task 17)	Enhanced capability to make best financial decision re type of freight car truck to purchase for a particular service	Better data on potential for operating cost reduction offered by various types of trucks under various operating conditions
	Improved quality and reduced cost of railway research	Improved ability to accurately evaluate the effects, on wheel wear, of changes to various operating components

*Benefits sufficient to provide an adequate return on the additional investment for retrofitting are only achievable in heavy haul, high mileage service in high curvature territory. CN Rail has had 100 retrofitted 100-ton coal cars in unit train service in British Columbia since 1979. 648 carsets have recently been acquired for similar service on the new BCR Tumbler Ridge Branch Line.

<u>Outcome of Research</u>	<u>Benefit</u>	<u>Basis for Benefit</u>
11. Identification of causes of crack initiation in 100-ton coal car truck bolsters (Task 18)	Increased safety and reduced truck maintenance costs	Implementation of measures to prevent crack initiation
<u>Track</u>		
12. Construction of a track structures test facility (Task 19)	Improved ability and reduced cost to conduct track structure and track component research	No interruption or hazard to revenue traffic. Experimental variables can be better controlled. Adjacent to Research Centre resources - shop, equipment, computer etc.
13. Improved understanding of the various methods of measuring track modulus and of the effect of various factors on modulus values (Task 21)	Progress towards an improved ability to define track upgrading requirements to cope with forecast traffic types and volumes	Improved capability to evaluate track strength
14. Improved understanding of the mechanics of rail wear and fatigue (Tasks 22, 23 and 24)	Progress towards reduction in track maintenance cost through increase in service life of rail	Progress towards improved specifications for the properties of rail steel
15. Data derived from studies re the manufacture and in-track performance of premium rail steels. (Tasks 26, 27 and 28)	Reduction in cost for rail replacement in curves in heavy traffic territories	Improved ability to make optimum choice of rail steel due to better knowledge of comparative service life of the various premium rails and the reasons therefor

<u>Outcome of Research</u>	<u>Benefit</u>	<u>Basis for Benefit</u>
16. Information gained from investigation into a non-destructive method for determining the thermal stress in long welded rails (CWR) at any time during their life in track. (Task 29)	Reduction in loss of traffic capacity	Reduction in frequency of rail grinding and/or replacement, and hence reduction in train delays
17. Method for heating CWR ahead of Rail Change Out Machine. (Task 30)	Progress towards a reduction in loss of traffic capacity and as well, a reduction in track maintenance cost	Ability to monitor stress in CWR, leading to a significant reduction in the incidence of "pull-aparts" and "buckling" and consequent reduction in train delays and labour to restore track to operating condition. (Work not yet complete)
18. Development of accurate easy-to-use rail profiler. (Tasks 31 and 32)	Reduced cost associated with laying CWR	Makes possible the welding together of plant-welded strings and the inclusion of insulated joints, prior to laying, thereby eliminating the need for subsequent in-track installation of thermit joints and insulated joints
	Reduction in loss of traffic capacity	Reduction in train delays through elimination of requirement to distress rail and install thermit joints and insulated joints after laying
	Improved quality and reduced cost of railway research	Improved ability to accurately evaluate effects on rail wear, of changes to various system components and parameters

Outcome of Research

19. Development of improved concrete track tie and installation (on CN) of more than 500,000 to date (Task 33)
20. Data derived from studies of ballast properties and subballast thickness (Tasks 34 and 36)
21. Data derived from studies of control of frost heaving by use of chemicals (Task 37)

Bridges

22. Information on actual stress levels in steel bridge members due to train loading (Task 38)
23. Identification of probable factors leading to crack initiation in bridge stringers (Task 38)

Benefit

- Reduced track maintenance cost
- Reduction in loss of traffic capacity
- Reduced track maintenance cost
- Reduction in loss of traffic capacity
- Progress towards reduction in loss of traffic capacity

Basis for Benefit

- Increased strength and durability of the improved tie
- Reduction in train delays due to track maintenance
- Increased strength of track structure
- Reduction in train delays because of reduced speed orders and/or track maintenance
- Progress towards reduction in delays because of reduced speed orders

- Reduced bridge maintenance cost

- Capability for more accurate design and analysis

- Increased safety and reduced bridge maintenance cost

- Implementation of measures to prevent crack initiation

<u>Outcome of Research</u>	<u>Benefit</u>	<u>Basis for Benefit</u>
<u>Vehicle and Train Dynamics</u>		
24. Data on the vibrational characteristics of freight cars and on the dynamic effects of unsprung weight on track loadings (Tasks 39 and 40)	Reduction in track and freight car maintenance costs. Reduction in derailments	Improved understanding of vehicle/track interaction leading to ability to reduce damaging force levels through improved vehicle/track design
	Enhanced research capability	Availability of computer program, developed during unsprung weight investigation, for further research
25. Methodology for instrumenting freight car and locomotive wheelsets and, as well, two instrumented freight car wheelsets. (Task 41)	Expanded scope and reduced cost of railway research	Ability to measure wheel/rail forces at any and all locations on system (as contrasted with ability to measure forces at only a single location using in-track instrumentation)
<u>Rail/Wheel Interface</u>		
26. Experimental rail/wheel wear apparatus and development of rolling contact computer simulation programs. (Tasks 43 and 44)	Progress towards reduction in railway operating costs through development of improved rail/wheel profiles, improved metallurgy and optimum lubrication practices	Expanded capability for rail/wheel wear investigations and improved understanding of wheel/rail contact mechanics

APPENDIX A - LIST OF TECHNICAL REPORTS

All of the technical reports prepared have been referenced in Section 4 under the individual basic task upon which they report. For the convenience of the researcher or other parties seeking information on a particular subject, e.g. freight car trucks, the following list of completed reports is provided, grouped by component/sub-component of the physical sub-system.

LOCOMOTIVE TRUCKS

"Curving Performance of SD-40-2 Locomotive Trucks", by W. Pak, Department of Research, Canadian Pacific Limited, June 1981.
CP Report No. - S677-81 TDC Report No. - TP3050

This report is also included as pages 169-195 of the Canadian Pacific final report on Phase IV, "Track/Train Dynamics Volume 2, 1981".
CP Report No. - None assigned TDC Report No. - TP3120

"Curving Performance Test of GM SD-40-2 and MLW M636 Locomotive Trucks", by W. Pak, R. Gonsalves and G. Izbinsky, Department of Research, Canadian Pacific Limited, April 1982.
CP Report No. - S715-82 TDC Report No. - TP3776E

This report is also included as pages 52-69 of the Canadian Pacific final report on Phase V, "Track/Train Dynamics Volume 3, 1982".
CP Report No. - None assigned TDC Report No. - TP4183E

"Effect of Axle Lateral Clearance and Wheel Profile Variation on the Curving Performance of SD-40-2 Locomotive Trucks", by W. Pak and R. Gonsalves, Department of Research, Canadian Pacific Limited.

This report was not published separately but is included as pages 70-112 of the Canadian Pacific final report on Phase V, "Track/Train Dynamics Volume 3, 1982".
CP Report No. - None assigned TDC Report No. TP4183E

"Technical Report Concerning Four Modifications to the SD-40-2 Locomotive Trucks to Reduce Track Loadings in Curves and Improve Ride", by Dynamic Sciences Limited, September 1981.

FREIGHT CAR TRUCKS AND WHEELS

"Test Report on the Comparative Curving Performance of Freight Car Trucks on Special Wheel Profiles", by P. Marcotte, CN Rail Research, March 1975.

CN Report No. - 122

TDC Report No. - None assigned

"Tests on B.C. South Line Clearwater Subdivision", by F. E. King, CN Rail Research, Feb. 28, 1975.

CN Report No. - 124

TDC Report No. - None assigned

"Track/Train Dynamics Report #3 - Testing of 100-Ton Bathtub Coal Cars Equipped with Hydraulic Interbogie Coupling Devices, April 30 - May 14, 1974", by R. Gonsalves, Department of Research, Canadian Pacific Limited, October 1974.

CP Report No. - S485-74

TDC Report No. - None assigned

This report is also included as Section C of the Canadian Pacific final report on Phase I "Track/Train Dynamics Phase I", March 1975.

CP Report No. - None assigned

TDC Report No. - None assigned

"Track/Train Dynamics Report #3A - Test on 100-Ton Bathtub Coal Car Equipped with Hydraulic Interbogie Coupling and Sideframe Stabilizers on November 28, 1974", by R. Gonsalves, Department of Research, Canadian Pacific Limited, March 1975.

CP Report No. - S492-75

TDC Report No. - None assigned

"Theoretical Study Concerning the Use of Profiled Wheels on Freight Car Trucks", by P. Marcotte, CN Rail Research, Aug. 2, 1973.

CN Report No. - 115

TDC Report No. - None assigned

"Wheel Profile Test on Luscar CN 199000 Series Coal Gondolas - Hunting Tests November 1975" by W. N. Caldwell and J. L. Bousquet, CN Rail Research, April 1976.

CN Report No. - M126

TDC Report No. - None assigned

"Wheel Profile Test on Luscar Coal Service Gondolas - Progress Report #1", by P. Marcotte and R. Mathewson, CN Rail Research, March 18, 1976.

CN Report No. - M125

TDC Report No. - None assigned

"Wheel Profile Service Test Luscar Coal Service Gondolas, Wheel Wear Measurements - Progress Report #2", by W. N. Caldwell, P. Marcotte, R. Mathewson, CN Rail Research, June 14, 1976.

CN Report No. - M128

TDC Report No. - None assigned

"Wheel Profile Test - Luscar Coal Service Gondolas, Wheel Wear Measurements (39,500 miles) - Progress Report #3", by P. Marcotte and K.J.R. Mathewson, CN Rail Research, January 1977.

CN Report No. - M132

TDC Report No. - None assigned

"Experimental and AAR Wheel Profile Measurements on a CP Unit Coal Train - Interim Report", by G. Izbinsky and W. Pak, Department of Research, Canadian Pacific Limited, July 1980.

CP Report No. - S-644-80

TDC Report No. - TP2728

This report is also included as pages 69-114 of the Canadian Pacific final report on Phase IV, "Track/Train Dynamics Volume 2, 1981".

CP Report No. - None assigned

TDC Report No. - TP3120

"Experimental 'A' and 'AAR' Wheel Profile Measurements on a CP Unit Coal Train - Final Report", by V. Khatchadourian, Department of Research, Canadian Pacific Limited, November 1983.

CP Report No. - S790-83

TDC Report No. - TP5081E

"Measurement of Angle-of-Attack With Lasers", by J. Kalousek and L. M. Yee, Department of Research, Canadian Pacific Limited, September 1977.

CP Report No. - S552-77

TDC Report No. - TP1225

This report is also included as pages 157-183 of the Canadian Pacific final report on Phase II, "Track/Train Dynamics Volume 1, 1978".

CP Report No. - None assigned

TDC Report No. - TP4576E

"Wheelset Angle-of-Attack Measurement of Regular Train Consists", by W. Pak, G. Izbinsky and H. Soares, Department of Research, Canadian Pacific Limited.

This report was not published separately but is included as pages 113-123 of the Canadian Pacific final report on Phase V, "Track/Train Dynamics Volume 3, 1982".

CP Report No. - None assigned

TDC Report No. - TP4183E

"Rail Replacement Costs on the B. C. South Line" by F. E. King, CN Rail Research, May 1976.

CN Report No. - 147

TDC Report No. - None assigned

"Effect of 100-ton Carloadings on Train Accident Costs - B. C. South Line" by F. E. King and C. J. Dalton, CN Rail Research, June 1976.

CN Report No. - 143

TDC Report No. - None assigned

"Effect of 100-ton Carloadings on Tie Replacement Costs - B. C. South Line" by F. E. King, CN Rail Research, May 1977.

CN Report No. - 150

TDC Report No. - None assigned

"Track Maintenance Cost, B. C. South Line, 1964 - 1974 inclusive - Summary Report" by F. E. King and C. J. Dalton, CN Rail Research, September 1977.

CN Report No. - 144

TDC Report No. - TP1222

"Articulated Truck Development" by P. Marcotte and W. N. Caldwell, CN Rail Research, June 3, 1977.

CN Report No. - 136

TDC Report No. - TP1221

"Performance Analysis and Testing of a Conventional Three-Piece Freight Car Truck Retrofitted to Provide Axle Steering", by P. Marcotte and W. N. Caldwell, CN Rail Research, and H. A. List, Railway Engineering Associates Inc., November 1978.

CN Report No. - 154

TDC Report No. - TP1988

"Development and Testing of DR-1 Self-Steering Freight Car Truck" by W. N. Caldwell, CN Rail Research, and D. W. Dibble, Transport Canada Research and Development Centre. Proceedings of the 5th Symposium on Engineering Application of Mechanics, Research Council of Canada, Ottawa, June 1981.

"Acquisition and Evaluation of Articulated Trucks on a Large Scale in Unit Train Service, Phase I" by R. P. Rennie, CN Rail Research, March 31, 1983.

CN Report No. - None assigned

TDC Report No. - TP4232E

"Contribution of Self-Steering Trucks to Wheel Wear Reduction: CN Experience" by W. N. Caldwell. Proceedings of the International Conference on Contact Mechanics and Wheel/Rail Wear, Vancouver, B.C., July 6-9, 1982.

"The Development and Testing of a Steering Type Freight Car Truck for Heavy Service" by W. N. Caldwell, G. W. Cope and H. A. List. Proceedings of the Second International Heavy Haul Railway Conference, Colorado Springs, Colorado, Sept. 25 to Sept. 30, 1982.

"The Evaluation of Self-Steering Trucks in Revenue Service Operation; CN Experience" by R. W. Radford and W. N. Caldwell. Proceedings of the Conference on The Economics and Performance of Freight Car Trucks, Montreal, Canada, October 25 - 27, 1983.

"Comparative Performance of Type 11 Trucks", by H. Ghonem and R. Gonsalves, Department of Research, Canadian Pacific Limited, November, 1978.

CP Report No. - S576-81

TDC Report No. - TP2372

This report is also included as pages 184-308 of the Canadian Pacific final report on Phase II, "Track/Train Dynamics Volume 1, 1978".

CP Report No. - None assigned

TDC Report No. - 4576E

"Railroad Dynamics Incorporated (RDI) Truck Evaluation Test", by R. Gonsalves, W. Pak and G. Izbinsky, Department of Research, Canadian Pacific Limited, March 1981.

CP Report No. - S670-81

TDC Report No. - TP2970

This report is also included as pages 1-68 of the Canadian Pacific final report on Phase IV, "Track/Train Dynamics Volume 2, 1981.

CP Report No. - None assigned

TDC Report No. - TP3120

"Elasto-Cushion Truck Performance Study", by R. Gonsalves, W. Pak and G. Izbinsky, Department of Research, Canadian Pacific Limited, October 1982.

CP Report No. - S714-82

TDC Report No. - TP3283E

This report is also included as pages 1-23 of the Canadian Pacific final report on Phase V, "Track/Train Dynamics Volume 3, 1982".

CP Report No. - None assigned

TDC Report No. - TP4183E

"Theoretical Curving Performance of Four Freight Car Trucks", by W. Pak and G. Rosval, Department of Research, Canadian Pacific Limited, December 1981.

CP Report No1 - S712-82

TDC Report No. - TP3449

This report is also included as pages 24-51 of the Canadian Pacific final report on Phase V, "Track/Train Dynamics Volume 3, 1982".

CP Report No. - None assigned

TDC Report No. - TP4183E

"Radial Axle Truck Tests", V. Khatchadourian, Department of Research, Canadian Pacific Limited, December 1983.

CP Report No. - None assigned

TDC Report No. - TP5271E

"Curving Performance Analysis of Freight Car Trucks" by R. Young and P. Marcotte, DSL Dynamic Sciences, September 1981.

DSL Report No. - None assigned

TDC Report No. - TP3211E

"Rail Wear Economic Analysis for Type 11 Trucks", by E. R. McIlveen et al., Canadian Institute of Guided Ground Transport, August 1982.

CIGGT Report No. - 82-3

TDC Report No. - TP3863E

"A Wheel/Rail Profilometer System, Vol. 1 and 11", by G. Izbinsky, H. Shrenkinger and H. Soares, Department of Research, Canadian Pacific Limited, February 1984.

CP Report No. - T-805-84

TDC Report No. - TP5229E

"Study of Crack Initiation in 100-ton Coal Car Truck Bolsters", by H. Ghonem, Department of Research, Canadian Pacific Limited, March 1978.

CP Report No. - S561-78

TDC Report No. - TP1681

This report is also included as pages 1-63 of the Canadian Pacific final report on Phase II, "Track/Train Dynamics Volume 1, 1978".

CP Report No. - None assigned

TDC Report No. - TP4576E

TRACK

"Lateral Strength Evaluation of Conventional Track Fastening System" by J. R. Lundgren and J. F. Scott, CN Rail Research, September 1973.
CN Report No. - M111 TDC Report No. - None assigned

"Static Track Gauge Widening Tests, October 1972, Lateral Strength of Track" by J. R. Lundgren, CN Rail Research, December 1972.
CN Report No. - 109 TDC Report No. - None assigned

"Track Structures Test Facility, Progress Report No. 5, The Measurement of Track Modulus", by A. Charenko and J. F. Scott, CN Rail Research, January 1982.
CN Report No. - 165 TDC Report No. - TP3586

"Track/Train Dynamics Report #4 - Rail Corrugations" by J. Kalousek, Department of Research, Canadian Pacific Limited, February 1975.
CP Report No. - S488-75 TDC Report No. - None assigned

This report is also included as Section E of the Canadian Pacific final report on Phase I, "Track/Train Dynamics Phase I", March 1975.
CP Report No. - None assigned TDC Report No. - None assigned

"High Speed Filming of Wheel/Rail Interaction" by J. Kalousek, National Research Council of Canada, Division of Mechanical Engineering, Vancouver, B.C., and R. Gonsalves, Department of Research, Canadian Pacific Limited, March 1978.
CP Report No. - S557-78 TDC Report No. - TP1474

"Dynamic Measurements of a Heavy Car Wheelset Over Rails Subject to Corrugation" by F. B. Blader, Railway Laboratory, National Research Council of Canada.
NRC Report No. - None assigned TDC Report No. TP1394

"Track/Train Dynamics Report #6, Rail Metallurgy", by J. Kalousek, Department of Research, Canadian Pacific Limited, and G. Beynon, Cominco Ltd., July 1975.
CP Report No. - S497-75 TDC Report No. - None assigned

This report is also included as pages 64-109 of the Canadian Pacific final report on Phase II, "Track/Train Dynamics Volume 1, 1978".
CP Report No. - None assigned TDC Report No. - TP4576E

"Rail Wear Under Heavy Traffic Conditions" by J. Kalousek and A. E. Bethune, Department of Research, Canadian Pacific Limited.
A paper presented at the Symposium on Steel, Stainless Steel and Related Alloys, sponsored by ASTM Committee A1, Denver, Colo., Nov. 1976 and included in ASTM Special Technical Publication STP644.

"Establishment of Quantitative Wear and Fatigue Model for Railway Rail, 1981/82 Progress Report" by J. Kalousek and H. Ghonem, April 1983. (NRC Report No. - LTR-WE-38, TDC Report No. - TP4347E). This report consists of five papers on the subject of rail wear, as follows:

"Observations of Rail Wear on Heavy Haul Railway Lines", by H. Ghonem, J. Kalousek, D. H. Stone, D. Dibble, Proceedings of the International Symposium on Contact Mechanics and Wear of Rail/Wheel Systems, University of Waterloo - Solid Mechanics Division, 1983.

"Aspects of Plastic Deformation and Fatigue Damage in Pearlitic Rail Steels", by H. Ghonem, J. Kalousek, D. H. Stone, E. E. Laufer; Proceedings of the Second International Heavy Haul Conference, ASME 82-HH-31.

"Lubrication: Its Various Types and Effects on Rail/Wheel Forces and Wear", by J. Kalousek; Proceedings of the Rail and Wheel Lubrication Symposium, Railway Systems and Management Association, 1982.

"Lateral Creepage and its Effect on Wear in Rail/Wheel Interface", by J. Kalousek, G. Rosval, H. Ghonem; Proceedings of the International Symposium on Contact Mechanics and Wear of Rail/Wheel Systems, University of Waterloo - Solid Mechanics Division, 1983.

"On the Fracture and Wear Characteristics of Chromium - Molybdenum Bainitic Steels", by H. Ghonem, J. Kalousek, D. H. Stone; Proceedings of the International Conference on Recent Developments in Specialty Steels and Hard Materials, Pretoria, 1982.

"Study of Fatigue Characteristics of Rail Steel", by H. Ghonem and W. Pak, Department of Research, Canadian Pacific Limited.

This report was not published separately but is included as pages 1-11 of the Canadian Pacific final report on Phase III, "Final Report, Track/Train Dynamics Program, Phase III, 1st October 1978 - 15th May, 1979".

CP Report No. - S601-79

TDC Report No. - TP2437

"Manual for Three-Dimensional Sub-Surface Contact Stress Analysis Program for Wheel/Rail Interaction", by W. Pak, Department of Research, Canadian Pacific Limited, October 1980.

CP Report No. - S659-80

TDC Report No. - TP2792

This report is also included as pages 115-168 of the Canadian Pacific final report on Phase IV, "Track/Train Dynamics Volume 2, 1981".

CP Report No. - None assigned

TDC Report No. - TP3120

"The use of Angle-of-Attack Measurements to Estimate Rail Wear under Steady State Rolling Conditions" by H. Ghonem, Department of Research, Canadian Pacific Limited, and J. Kalousek, National Research Council. Proceedings of International Conference on Wheel/Rail Load and Displacement Measurement Techniques, Boston, Mass., Jan. 19-20, 1981, U. S. Department of Transportation Publication DOT-TSC-UMTA-82-3.

"Development of a New Rail Curve Grease" by C. Smith, Imperial Oil.

This report was not published separately but is included as pages 18-28 of the Canadian Pacific final report on Phase III, "Final Report, Track/Train Dynamics Program, Phase III, 1st October 1978 - 15 May 1979".
CP Report No. S601-79 TDC Report No. TP 2437

"A Novel Approach to Rail Lubrication" by R. G. Nkana, Department of Mechanical Engineering, McGill University, August 1976. (not numbered)

"Evaluation of Premium Rail on 8 degree Curves on the B. C. South Line" by P. M. Gardiner, R. G. Butler, C. J. Dalton and J. F. Scott, CN Rail Research, January 1979.
CN Report No. - 152 TDC Report No. - TP2567

"Premium Rails: A Review of Options", by L. P. Trudeau, D.W.G. White, W. J. Craigen, Canada Centre for Mineral and Energy Technology (CANMET), Report No. - MRP75-14 (ACT) (TR) (CF) TDC Report No. - None assigned

"Report on Development of High Strength Weldable Chromium-Molybdenum Rail", by H. Ghonem, Department of Research, Canadian Pacific Limited and J. Kalousek, Western Laboratory, Division of Mechanical Engineering, National Research Council, August 1978.
CP Report No. - S571-78 TDC Report No. - None assigned

This report is also included as pages 110-156 of the Canadian Pacific final report on Phase II, "Track/Train Dynamics Volume 1, 1978".
CP Report No. - None assigned TDC Report No. - TP4576E

"Effects of 'Streaks' on the Fracture Toughness of Chromium-Molybdenum Rail Steel" by J. Kalousek, Western Laboratory, Division of Mechanical Engineering, National Research Council and D. E. Parsons and H. Ghonem, Department of Research, Canadian Pacific Limited, August 1980.
CP Report No. - S651-80 TDC Report No. - TP2726

This report is also included as pages 196-212 of the Canadian Pacific final report on Phase IV, "Track/Train Dynamics Volume 2, 1981".
CP Report No. - None assigned TDC Report No. - TP3120

"Evaluation of Algoma Cro-Mo Rail Steel for Canadian Pacific Railroad" by F. B. Fletcher, Climax Molybdenum Company, Jan. 23, 1976.
Report No. - J-4183. Copy held in TDC library.

"On the Performance of the Experimental Bainitic Chromium-Molybdenum Rail Steel", by H. Ghonem, Department of Research, Canadian Pacific Limited, April, 1982.
CP Report No. - S739-82 TDC Report No. - TP3726E

This report is also included as pages 124-153 of the Canadian Pacific final report on Phase V, "Track/Train Dynamics Volume 3, 1982".
CP Report No. - None assigned TDC Report No. - TP4183E

"A Perspectival Review of Rail Behaviour at the Facility for Accelerated Service Testing", by R. K. Steele, Transportation Test Centre, Pueblo, Colo., June 19, 1981.
Report No. FRA/TTC-81/07 (NTIS PB82 176470)

"On the Fracture and Wear Characteristics of Chromium-Molybdenum Bainitic Steels", by H. Ghonem, University of Rhode Island, J. Kalousek, National Research Council of Canada and D. H. Stone; Proceedings of the International Conference on Recent Developments in Specialty Steels and Hard Materials, Pretoria, 1982.

Note: A copy of this paper is included in the NRC report "Establishment of Quantitative Wear and Fatigue Model for Railway Rail - 1981/82 Progress Report".

NRC Report No. - LTR-WE-38

TDC Report No. - TP4347E

"Alloy Rail Production - Visit to European Producers", by G. F. Morris and H. Jaeger, Algoma Steel Corporation and L. Trask, Sydney Steel Corporation, March 16, 1976. This is an informal letter-type report. Copy held in TDC library.

"Analysis of P-65 Rail - Preliminary Report", by H. Ghonem, Department of Research, Canadian Pacific Limited, October 1979.

CP Report No. - S606-79

TDC Report No. - None assigned

This report is also included as pages 213-239 of the Canadian Pacific final report on Phase IV, "Track/Train Dynamics Volume 2, 1981".

CP Report No. - None assigned

TDC Report No. - TP3120

"Field Evaluation of the Wear Performance of Russian P-65 Rail - Interim Report", by G. Rosval, Department of Research, Canadian Pacific Limited.

CP Report No. - S750-83

TDC Report No. - None assigned

"Examination of Russian P-65, Oil Quenched, Tempered, Carbon-Steel 'Exchange' Rail", by D. E. Parsons et al., Physical Metallurgy Research Laboratories, CANMET, August 1980.

CANMET Report No. - MRP/PMRL 80-28(CF)

TDC Report No. - None assigned

"Field Evaluation of the Wear Performance of Russian P-65 Rail", by K. Griffin, Department of Research, Canadian Pacific Limited, December, 1983.

CP Report No. - S799-83

TDC Report No. - None assigned
at time of writing of this
Summary Report.

"Determination of Stress-Free Temperatures and Force Levels in Continuous Welded Rail (CWR)" by J. F. Scott and C. J. Dalton, CN Rail Research, May 1982.

CN Report No. - 176

TDC Report No. - 3707E

"Rail Wear Measurement - Precision Rail Profilometer", by K.J.R. Mathewson, CN Rail Research, July 28, 1977.
CN Report No. - M134 TDC Report No. - TP1223

"Concept of a Profilometer for Rail Wear Determination", by G. Izbinsky and G. Warshaw, Department of Research, Canadian Pacific Limited, December 1981.
CP Report No. - S655-81 TDC Report No. - TP3503

This report is also included as pages 154-186 of the Canadian Pacific final report on Phase V, "Track/Train Dynamics Volume 3, 1982".
CP Report No. - None assigned TDC Report No. - TP4183E

"A Wheel/Rail Profilometer System, Vol. I and II", by G. Izbinsky, H. Sheekinger and H. Soares, Department of Research, Canadian Pacific Limited, February 1984.
CP Report No. - T-805-84 TDC Report No. - TP5229E

"Track Structures Test Facility, Test Report No. 1, Displacement of Newly Constructed Concrete Tie Track Under Static Lateral Load (Zero Vertical Load)" by J. F. Scott, CN Rail Research, January 1976.
CN Report No. - 131 TDC Report No. - None assigned

"Track Structures Test Facility, Test Report No. 2, Displacement of Newly Constructed Concrete Tie Track under Dynamic Lateral Load (Zero Vertical Load)" (Anon.), March 1977.
CN Report No. - 135 TDC Report No. - TP1330

"Track Structures Test Facility, Test Report No. 3, Performance of Concrete Tie Track Structure Under Repeated Low Speed Heavy Rolling Load" by A. Charenko and J. F. Scott, CN Rail Research, October 1977.
CN Report No. - 139 TDC Report No. - TP1331

"Use of Resilient Fastenings for Wood Ties as an Alternative to Concrete Ties - An Economic Comparison" by F. E. King, CN Rail Research, December 1976.
CN Report No. 142 TDC Report No. - None assigned

"Track Structures Test Facility, Progress Report No. 4, Concrete Tie Centre Bending Moments with Track Settlement and Frost Heave" by A. Charenko and J. F. Scott, CN Rail Research, November 1980.
CN Report No. - 162 TDC Report No. - TP2650

"Freeze-Thaw Tests on Concrete Ties" by C. R. Duggan, C. J. Dalton and J. F. Scott, CN Rail Research, July 1979.
CN Report No. - 155 TDC Report No. - TP2269

"Measurement of Concrete Tie Centre Bending Deflection Kingston, Albreda and Rivers Subdivisions, May 1978" by J. F. Scott and A. Charenko, CN Rail Research, September 1978.
CN Report No. - 151 TDC Report No. - TP2628

- "Characteristics of the CN60A Concrete Cross Tie" by J. F. Scott, CN Rail Research, November 1980.
CN Report No. - 160 TDC Report No. - TP2647
- "Impact Loading Measurements on CN60A Concrete Cross Ties - Progress Report" by J. F. Scott, CN Rail Research, November 1980.
CN Report No. - 163 TDC Report No. - TP2649
- "Measurement of Concrete Tie Centre Bending Deflections Kingston, Albreda and Rivers Subdivisions July 1979", by A. Charenko and J. F. Scott, CN Rail Research, February 1980.
CN Report No. - 159 TDC Report No. - TP2583
- "Measurement of Concrete Tie Centre Bending Deflections Albreda and Rivers Subdivisions September 1980", by A. Charenko and J. F. Scott, CN Rail Research, September 1981.
CN Report No. - 174 TDC Report No. - TP3346
- "1980 Laboratory Research on Concrete Ties" by J. F. Scott, CN Rail Research, November 1981.
CN Report No. - 175 TDC Report No. - TP3585
- "Petrographic Study of Ballasts" by Jean Berard Ph.D., Ecole Polytechnique, Sept. 10, 1973.
CN Report No. - 130 TDC Report No. - None assigned
- "Field Durability Tests on Ballast Samples as a Guide to the Significance of the Specification Requirements" by C. J. Dalton, CN Rail Research, January 1973.
CN Report No. - 110 TDC Report No. - None assigned
- "Crushed Rock Ballast Densification Tests" by N. Caldwell and C. J. Dalton, CN Rail Research, March 1974.
CN Report No. - 118 TDC Report No. - None assigned
- "Freeze-Thaw Tests on Ten Ballast Samples" by C. J. Dalton, CN Rail Research, June 1976.
CN Report No. - 133 TDC Report No. - None assigned
- "Strength Tests on Crushed Rock Ballast" by C. J. Dalton, CN Rail Research, April 1977.
CN Report No. - 138 TDC Report No. - TP984
- "Modification to a Standard Ballast Regulator as an Aid to Trowelling" by W. J. Wood, W. Bowler and C. J. Dalton, CN Rail Research, (no date).
CN Report No. - 117 TDC Report No. - None assigned
- "Dynamic Triaxial Testing Program, Present Status" by D. E. Sheeran, Geotechnical Research Centre, McGill University, July 15, 1979.
CN Report No. - None assigned TDC Report No. - Not yet assigned

"Predicting Requirements for Subballast Thickness, Progress Report No. 1, Measurements of Track Loads and Deflections Edmonton, Alberta, May 1979" by C. J. Dalton and J. F. Scott, CN Rail Research, February 1980.
CN Report No. - 158 TDC Report No. - TP2584

"Prediction of Long Term Track Subgrade Settlement Due to Cyclic Wheel Loading" by D. E. Sheeran, H. H. Elamlouk and E. A. Fattah, Geotechnical Research Centre, McGill University, November 1980.
CN Report No. - 164 TDC Report No. - TP2648

"Predicting Requirements for Subballast Thickness, Progress Report No. 2, Measurement of Track Loads and Deflections Edmonton, Alberta, June 1980, L'Assomption, Quebec, August 1980", by C. J. Dalton and J. F. Scott, CN Rail Research, April 1981.
CN Report No. - 166 TDC Report No. - TP2987

"An interim Report for the Design of Ballast Thickness Under Adverse Conditions", by D. E. Sheeran and R. Jayarman, Geotechnical Research Centre, McGill University, September 1981.
CN Report No. - 177 TDC Report No. - TP3766E

"Predicting Requirements for Subballast Thickness, Progress Report No. 3, Measurements of Railroad Track Loads, Roadbed Dynamic Deflections and Settlements" by J. F. Scott, CN Rail Research, March 1983.
CN Report No. - 179 TDC Report No. - TP4350E

"Performance of Frost Heave Modifying Chemical Additives at the CN Dorval Test Site" by D. E. Sheeran and R. N. Yong, Geotechnical Research Centre, McGill University, October 1978.
CN Report No. - 149 TDC Report No. - TP1814
McGill Geotechnical Research Centre Report No. - FHTD-VIII.

Other valuable information on this work is contained in the following McGill University Geotechnical Research Centre Reports:

"Alleviation of Detrimental Frost Heaving of Soils by Chemical Treatment" by Raymond N. Yong and Donald E. Sheeran, January 1978.
McGill Research Report No. - None assigned TDC Report No. - TP1408

"The use of Precipitants to Decrease the Rate of Migration of Frost Heave Modifying Additives" by Raymond N. Yong and Donald E. Sheeran, Geotechnical Research Centre, McGill University, April 1976.
McGill Research Report No. - FHTD-VI TDC Report No. - None assigned

BRIDGES

"Track/Train Dynamics Report #2 - Testing of Bridges at Mileages 1.7 and 31.4 Shuswap Subdivision", by Department of Research, Canadian Pacific Limited, October 1973.

CP Report No. - S460-73

TDC Report No. - None assigned

This report is also included as Section B of the Canadian Pacific final report on Phase I - "Track/Train Dynamics Phase I", March 1975.

CP Report No. - None assigned

TDC Report No. - None assigned

"Track/Train Dynamics Report #5 - Measurements of Bridge Pier Displacement Using Laser Technology", by J. Kalousek and R. Gonsalves, Department of Technical Research, Canadian Pacific Limited, March 1975.

CP Report No. - S491-75

TDC Report No. - None assigned

This report is also included as Section F of the Canadian Pacific final report on Phase I - "Track/Train Dynamics Phase I", March 1975.

CP Report No. - None assigned

TDC Report No. - None assigned

"Stringer Stress Measurements on Bridge, Mile 51.5 Windermere Subdivision", by J. Kalousek and A. E. Bethune, Department of Research, Canadian Pacific Limited, (no date).

This report was not published separately but is included as pages 362-398 of the Canadian Pacific final report on Phase II, "Track/Train Dynamics Vol. 1, 1978".

CP Report No. - None assigned

TDC Report No. - TP4576E

VEHICLE AND TRAIN DYNAMICS

"Track/Train Dynamics, Report #1 - Natural Frequencies of Vibration, Heavy Freight Cars" by Department of Research, Canadian Pacific Limited, (author's name not given), June 1974.

CP Report No. - S456-73

TDC Report No. - None assigned

This report is also included as Section A of the Canadian Pacific final report on Phase I - "Track/Train Dynamics, Phase I", March 1975.

CP Report No. - None assigned

TDC Report No. - None assigned

"Effect of Unsprung Weight on Vertical Track Dynamics", by J. Robert, Department of Research, Canadian Pacific Limited (Interim Report).

CP Report No. - None assigned

TDC Report No. - TP1224

This report is also included as pages 309-322 of the Canadian Pacific final report on Phase II, "Track/Train Dynamics Vol. I, 1978".

CP Report No. - None assigned

TDC Report No. - TP4576E

RAIL/WHEEL INTERFACE

"Experimental Rail/Wheel Wear Apparatus" by J. Kalousek, National Research Council.

This is a progress report on the development of the apparatus. It was not published separately but is included as pages 55-57 of the Canadian Pacific final report on Phase III, "Final Report, Track/Train Dynamics Program Phase III, 1st October 1978 - 15 May 1979".

CN Report No. S601-79

TDC Report No. - TP2437

"Analytical Studies of the Rail-Wheel System. An Overview of Applications of Rolling Contact Theory", Department of Research, Canadian Pacific Limited.

This report was not published separately but is included as pages 187-192 of the Canadian Pacific final report on Phase V, "Track/Train Dynamics Volume 3, 1982".

CP Report No. - None assigned

TDC Report No. - TP4183E

APPENDIX B - WORK STATEMENT

TRANSPORTATION DEVELOPMENT CENTRE

WORK STATEMENT

TRACK/TRAIN DYNAMICS PROGRAM SUMMARY REPORT

1. INTRODUCTION

A major planning effort on track train dynamics was initiated in July 1971 by the Southern Pacific under contract to the AAR. The plan was completed in early 1972 and proposed a ten-year research effort into track train dynamics. The plan, to be conducted over a 10-year span, indicated that no individual railway had the resources to undertake the entire program. Therefore, the AAR proceeded to set up the TTD Steering Committee, having representatives from AAR, FRA, RPI and TDC.

TDC agreed to commit itself to the program through membership on the Steering Committee and by conducting associated research with CN and CP.

The program had an estimated duration of 10 years. This time span has now past and although the TTD program is continuing it is appropriate, after 10 years that the Canadian achievements be summarized for ease of reference.

2. OVERALL OBJECTIVE

To ensure maximum technology transfer of the results of the cooperative Canadian TTD program that TDC has sponsored with both CN and CP.

3. PROJECT OBJECTIVE

The project objective is to prepare a program summary report of the results of the Track Train Dynamics research which CN and CP have undertaken in cooperation with TDC since the beginning of the TTD program approximately 10 years ago.

4. DETAILED STATEMENT OF WORK

The work constituting this project shall include the following elements:

- 4.1 Develop a detailed work plan, activity schedule and documentation procedures within 4 weeks of effective commencement date.
- 4.2 Review all files, relating to each of the following contracts, to identify tasks undertaken:

- i) TDC/CN Track Train Dynamics Contracts Phase I to 9.
- ii) TDC/CN Contract, "Articulated Truck Development and Evaluation".
- iii) TDC/CP Track Train Dynamics Contracts Phases 1 to 5.
- iv) TDC/CP Contract, "Radial Truck Evaluation".
- v) Joint TDC/FRA Truck Design Optimization Project Contracts
 - CIGGT, "Rail Wear Economic Analysis"
 - DSL Dynamic Sciences Ltd., "Curving Performance Analysis of Freight Car Trucks".

- 4.3 Prepare a list of all tasks undertaken in each contract.
- 4.4 Prepare a draft table of contents for approval by TDC.
- 4.5 Summarize the activities that occurred in each task.
- 4.6 Identify, review and reference, by task, all reports resulting from the contracts.
- 4.7 Describe the results/achievements of each task.
- 4.8 Discuss the results/achievements with CN, CP, etc., in order to assess their degree of impact on freight operations/research activities.
- 4.9 Provide a Track Train Dynamics program summary report containing material found in Sections 4.2 - 4.8 and progress reports as described in Section 8, "Reporting Requirements".

5. SPECIAL INSTRUCTIONS

In order that the results/achievements of the Track Train Dynamics program can be fully appreciated and assessed, interviews should be conducted with the key personnel, within CN and CP, who were involved/affected.

